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RADIOGRAPHY

AND THE 'X' RAYS

IN PRACTICE AND THEORY

WITH CONSTRUCTIONAL AND MANIPULATORY DETAILS

BY

S. R. BOTTONE

AUTHOR OF 'THE DYNAMO' 'ELECTRIC BELLS' 'ELECTRO-MOTORS'
'ELECTRICAL INSTRUMENTS' ETC.

WITH 47 ILLUSTRATIONS

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PREFACE

In the following pages, an attempt has been made to give a clear and trustworthy account of the steps that have led up to the discovery and application of those electric waves that are now known as 'X' rays. Every care has been taken to treat the subject with lucidity and accuracy, and to this end nearly every one of the statements made has been verified by personal experiment. Where this has been impossible of execution, the source of the statement, or the name of the experimenter, has been given. Considerable prominence has been given to constructional details and measurements, with the view of facilitating the student in making the apparatus necessary. No sensational matter, or far-fetched applications of radiography, insufficiently confirmed, have been admitted into this work; but full and at the same time clear explanations have been given, which, it is hoped, will render the subject easy of comprehension.

S. BOTTONE.

Wallington: *January* 1898.

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CHAPTER I

ON THE ACTION OF LIGHT ETC. ON CERTAIN SALTS OF SILVER

§ 1. Certain salts of silver,[1] notably the bromide, iodide, chloride, and fluoride, are sensitive to the action of *light*.[2] In other words, the molecular constitution of these compounds is so far altered by the effect of light acting upon them, that either directly (by the sole influence of light) or indirectly (by the continuating action of a 'developer' or 'reducing agent') the silver salt finally splits up into its two components—viz., metallic silver on the one hand, and bromine, iodine, chlorine, or fluorine on the other. This property constitutes the basis of ordinary photography.

[1] And many other bodies, as, for example, chromic salts, ferric salts, vegetable colouring matters, many of the aniline colouring derivatives, &c.

[2] Strictly speaking, it is only the more highly refrangible rays of light, such as the blue, the violet, and the ultra-violet, that have any marked effect on the majority of these so-called 'sensitive silver salts.'

§ 2. This power of decomposing or starting the decomposition of these salts of silver is by no means limited to the agency which we call light. It is shared, in greater or lesser degree, by *heat*, *electricity* (and its correlative, *magnetism*), by *mechanical pressure*, or *friction*.

§ 3. In order that the student may be able to verify experimentally the above statements, a few simple directions are given by means of which he can produce images in these varied manners. In 1880 Captain Abney published in the 'Philosophical Transactions' an account the method of preparing an emulsion of silver bromide in collodion. This emulsion is sufficiently sensitive to *heat* to give distinct images of any devices or perforations cut out in a sheet of cardboard, placed over a plate coated with the emulsion, when a blackened kettle containing boiling water is held at a little distance from the perforated cardboard screen. To the end that no possibility should arise of the result being due either to mechanical disturbance by the pressure of the cardboard, or to any chemical action of any substance contained therein, the screen should not be in actual contact with the sensitive plate, but should be separated from it by a distance of about $\frac{1}{8}$ in. In like manner the kettle should be raised at least $\frac{1}{2}$ in. from the surface of the cardboard screen. It is needless to remark that this experiment should be performed in the photographer's 'dark room,' to prevent light affecting the plate.

The preparation of the special emulsion which

is sensitive to the heat rays is thus given by Captain Abney.

'A normal collodion is first made according to the formula below:—

Pyroxyline (any ordinary kind) . . .	16 gr.
Ether (·725)	4 oz.
Alcohol (·820)	2 oz.

This is mixed some days before it is required for use, and any undissolved particles are allowed to settle, and the top portion is decanted off. Three hundred and twenty grains of pure zinc bromide are dissolved in $\frac{1}{2}$ oz. to 1 oz. of alcohol (·820), together with 1 drachm of nitric acid. This is added to 3 oz. of the above normal collodion, which is subsequently filtered. Five hundred grains of silver nitrate are next dissolved in the smallest quantity of hot distilled water, and 1 oz. of boiling alcohol ·820 added. This solution is gradually poured into the bromized collodion, stirring briskly while the addition is being made. Silver bromide is now partially suspended in a fine state of division in the collodion, and if a drop of the fluid be examined by transmitted light it will be found to be of an orange colour.

'Besides the suspended silver bromide, the collodion contains zinc nitrate, a little silver nitrate, and nitric acid, and these have to be eliminated. The collodion emulsion is turned out into a glass flask, and the solvents carefully distilled over with the aid of a water-bath, stopping the operation when the whole solids deposit at the bottom of the flask. Any liquid remain-

ing is carefully drained off, and the flask filled with distilled water. After remaining a quarter of an hour the contents of the flask are poured into a well-washed linen bag, and the solids squeezed as dry as possible. The bag with the solids is again immersed in water, all lumps being crushed previously, and after half an hour the squeezing is repeated. This operation is continued till the wash water contains no trace of acid when tested by litmus paper. The squeezed solids are then immersed in alcohol ·820 for half an hour to eliminate almost every trace of water, when, after wringing out as much of the alcohol as possible, the contents of the bag are transferred to a bottle, and 2 oz. of ether (·720) and 2 oz. of alcohol (·805) are added. This dissolves the pyroxyline, and leaves an emulsion of silver bromide, which when viewed in a film is essentially green-blue by transmitted light.

'All these operations must be conducted in a very weak red light—such a light, for instance, as is thrown by a candle shaded by ruby glass, at a distance of twenty feet. If a green light of the refrangibility of about halfway between E and D could be obtained it would be better than the faint red light transmitted by ruby glass, since the bromide is less sensitive to it than to the latter. The light coming through green glass after being filtered through stained red glass is almost the best light to use. It is most important that the final washing should be conducted almost in darkness. It is also essential to eliminate all traces of nitric acid, as it retards the action of the heat-rays on the bromide, and

may destroy it if present in any appreciable quantities. To prepare the plate with this silver bromide emulsion all that is necessary is to pour it over a clean glass plate, as in ordinary photographic processes, and to allow it to dry in a dark cupboard.

'It has been found advantageous to coat the plate in red light, and then to wash the plate and immerse it in a dilute solution of HCl, and again wash, and finally dry. These last operations can be done in dishes in absolute darkness; the hydrochloric acid renders innocuous any silver sub-bromide which may have been formed by the action of the red light, and which would otherwise simulate a heat image.

'The development of the plate is greatly more difficult than the preparation of the emulsion. A strong developer it will not stand, and I may say also that a very new one is inadmissible when using the ferrous oxalate development. To make the developer, a saturated solution of neutral oxalate of potash is saturated in the cold, with ferrous oxalate, and then the deep red solution decanted off. When freshly prepared it is useless to attempt to develop a plate with it unless the precaution be taken of adding to it an equal part of a saturated solution of ferric oxalate in the oxalate of potash. Such a mixture may be employed by adding to it immediately before all an equal volume of a solution of potassium bromide (20 grains of the salt to 13 of water). The plate may then develop without fog, or it may not; if it does fog, the development must have more bromide solution added to it, and another trial made. On some

days a clean picture seems an impossibility, whilst on others every one will be perfect. It is not the emulsion that is in fault, since on a "clear day" and on a "foggy day" the identical emulsion may be used, showing that the developer is at fault. This year this trouble seems to have increased, and I can only lay it down to the different preparations of the oxalates. Of one thing care should be taken—viz., that the developer never shows alkalinity; a drop of dilute sulphuric acid or nitric acid may be added to the developing cup just before development with advantage.'

§ 4. That *electricity* affects the photographic plate has long been known; and it is easy to get a picture of a non-luminous 'brush' discharge from a point affixed to a static electric machine (such as a plate machine, or a Wimshurst), or from one terminal of an induction coil, which for this purpose need not be a very powerful one, by simply holding an ordinary wet collodion or a dry plate for a second near the discharging point. This experiment should of course be performed in the 'dark room,' and care should be taken that no actual sparking takes place. If the experiment have been made with a wet collodion plate, the ordinary acid ferrous sulphate developer should be used to bring out the resulting picture; if a dry plate has formed the basis of the experiment alkaline pyro or ferrous oxalate may be employed as developers.

There is, however, another mode of producing pictures by means of electricity which the author has experimented with, and which, as he has not seen it described

or adverted to elsewhere, may be worthy of the reader's attention. This mode depends entirely upon INDUCTION, there being no actual *discharge* of electricity *through* or *along* the sensitive film of the plate itself; but around it is set up a state of varying electrical tension, which by *induction* produces a disturbance in the molecules of the sensitive film, in a manner precisely similar to that in which the rays of light[1] or heat act.

To obtain this effect, it is only necessary to place an ordinary gelatine bromide plate (Cadett's 'Lightning' plates will be found very good for this purpose) in one of Tylar's 'dark bags,' and then to place a piece of tinfoil, with some device cut out, on the outside of the black bag or envelope, on the surface nearer the film. On each side of the black bag is now placed a well-cleaned glass plate, which should be considerably larger than the bag. Both under the lower glass plate and over the upper one is now placed a sheet of tinfoil, about the same size as the sensitised plate. The whole sandwich is now laid on a table, and the lower tinfoil and the upper respectively put in circuit either with the terminals of a coil capable of giving at least 1 in. spark, or else with the outer coatings of the two Leyden jars of a Wimshurst or similar machine, the discharging knobs between the jars being so arranged as to spark at about 1 in. distance. The coil or the Wimshurst having been set in action, and about a dozen discharges allowed to

[1] With a great show of reason, Professor Oliver Lodge considers electricity and light to be one and the same thing. See *Modern Views of Electricity*.

take place, it will be found on retiring to the dark room, and submitting the plate to the action of the developer, that a very distinct image of the pattern or device will be the result. Here we see that the effect is purely electro-chemical, that no 'discharge' or 'spark' or other 'light' effect of electricity has any hand in the result. The upper and lower tinfoils get charged 'Leyden-jar fashion' during the experiment, and at each discharge they are seen to wave suddenly. The explanation of this noticeable phenomenon is that the loose sheets of tinfoil become respectively charged positively and negatively, and that to a certain extent the *surface* of the glass on which they rest has taken up a similar charge, and repels the tinfoil; at the instant of discharge, there being no repulsion, the tinfoil falls back again flat on the glass. It will be evident to any one acquainted with the rudiments of electricity that no real *current*, or even true discharge, takes place on the surface of the sensitive film; but it is probable that under the inductive effect of the oppositely charged tinfoil coatings the molecules of silver bromide are polarized; that at the instant of discharge they fall back into their old position; and that the repeated molecular disturbances or oscillations set up by the consecutive discharges, or 'changes of potential,' are sufficiently great to render the film amenable to the action of the developer at those portions not protected by the tinfoil, which, being of poor specific inductive capacity, cuts off to a considerable extent the influence of the upper charged tinfoil. Fig. 1 is from a photograph obtained by the means described above.

The following experiment by Mr. R. C. Shettle is interesting in this connection.

A No. 14 B.W.G. cotton-covered copper wire was bent five times upon itself in parallel lines. It was then fastened to a piece of cardboard by stitching it at

FIG. 1.—INDUCTION EFFECT (CROSS).

each bend and midway between the bends. A very thin magnetic strip was then placed across the back of a photographic plate, its position being maintained by small pieces of postage stamp paper. The photographic plate, with the magnet at its back, and the cardboard

with the wire attached as described, were next very carefully wrapped up in ruby paper, which was again covered with black paper, the wire on the surface of the cardboard resting on the sensitive surface of the photographic paper—*i.e.*, nothing intervened but the cotton with which the wire was covered. It should also be stated that previous to enfolding the apparatus in the paper the terminals of the wires were bent back upon the outer surface of the cardboard, and that the whole process was conducted by a photographer in his dark room. The terminals of the wires were then connected with the wires of a Fowler's alternator dynamo giving 40 periodicities per second, and a current of about 8 ampères was sent through the wire for about forty-seven minutes.

After the development of the results by the photographer on the following day examination showed not only the complete image of the magnetic strip, but of the stamp paper also by which it was affixed to the glass, together with a representation of the red line which exists near one edge of the paper and the segments of the perforations where the stamps had been torn away.

§ 5. Although not directly connected with radiography, it is well to notice that mere mechanical pressure is sufficient to bring about a molecular change in the constitution of certain bodies, notably certain salts of mercury as well as the silver salts mentioned in the previous sections. For example, there is a beautiful scarlet compound of mercury with iodine known as

mercuric iodide, which, if heated (after being spread on a sheet of paper by gentle pressure with a spatula, so as to produce an even layer), assumes a crystalline form, at the same time changing its brilliant scarlet for a dull primrose tint. This yellow colour is retained so long as the surface is not touched; but if the surface be now pressed, or rubbed, or scratched with a point, the molecular condition of the iodide of mercury is disturbed, and, losing its crystalline form, it reverts to the amorphous bright scarlet state. It is very interesting to notice this effect, since the action is not localised to the spot touched, but gradually extends itself to the whole film of iodide covering the sheet of paper, provided that film have been made fairly continuous. In July 1842, Mr. Moser of Königsberg showed that it is sufficient to place a body in contact with a sensitised daguerreotype plate (even in the dark) to be able to produce a distinct image of the body, on development of the plate. Dr. Draper, as early as September 1840, mentions a similar fact. Perhaps the most extraordinary point in connection with these phenomena is that it is not necessary that the body should be in actual contact with the daguerreotype plate to produce these results. In one experiment performed by Robert Hunt[1] it was shown that by placing upon a plate of polished copper a thick piece of plate glass, and over this a square of metal and then some other articles, each of which was rather larger than the one beneath, and then the whole covered by an inverted deal box, an image could be obtained.

[1] Hunt's *Photography*, 4th ed. p. 155.

The deal box was more than $\frac{1}{2}$ in. distant from the plate. Things were left in this position for a night. On developing the plate it was found that each article was copied, the bottom of the deal box more faithfully than any of the others, the grain of the wood being imaged on the plate. Attention is called here to these 'contact pictures,' not so much for any direct bearing they have upon radiography, but in order to prevent the student from being misled by the production of images which he may think due to the X ray effects of electricity or of magnetism, but which may be really due to contact or pseudo-contact only.

CHAPTER II

ON THE EFFECTS OF A PARTIAL VACUUM ON ELECTRICAL DISCHARGES

§ 6. When a current of electricity of sufficiently high pressure encounters in its passage an air space at any point of the circuit, light and heat are the results of this interruption in the circuit. To produce this result, if the electro-motive force be low, say, does not exceed from 50–100 volts, it is absolutely necessary that the points at which it is intended to produce the light should be in actual contact, and then gradually withdrawn. With such low pressures as those indicated, the distance to which the two points at which the 'arc' or light is produced can be separated is always very small, rarely exceeding $\frac{1}{8}$ in. But by increasing the E.M.F. the length of the arc may be increased, and when a pressure of some 12,500 volts has been reached, not only will the arc be produced, but it will strike across an air gap of about $\frac{1}{4}$ in., without requiring the points to be brought in actual contact. With higher voltages proportionately longer discharges through air can be obtained; it is roughly estimated

that it requires about 50,000 volts for every inch of air gap to be bridged; or, in other words, that for every inch of spark required in *ordinary air*, an E.M.F. of 50,000 volts will be needed. But if the points between which the arc is produced be enclosed in a tube or other glass vessel, capable of having the air contained within it gradually exhausted, it is found that the distance to which the points may be removed, without interrupting the flow of the current and the consequent production of visible light, may be increased up to a certain point with the increase in the rarefaction of the air in the containing tube or vessel. In fact, so low a pressure as 12,500 volts, which would give barely $\frac{1}{4}$ in. spark in air, will easily spark across a tube 6 in. in length, when the exhaustion has been carried to about $\frac{1}{15}$ of the original pressure of the air. Tubes of this kind, in which electrodes are fused in each end, and from which the air has been duly exhausted, have long been before the public, and are known as Geissler tubes or vacuum tubes. One noticeable peculiarity is that, as the vacuum increases, the brilliancy and directness of the discharge or arc decreases, the light produced being evidently due to the resistance met with by the current in traversing the air; and since this resistance becomes less as the air becomes more rarefied, so the light becomes less white and brilliant, passing gradually to bluish, and lastly to a ruddy violet, diffusing itself at the same time throughout the entire tube or containing vessel. If the vacuum be pushed far enough, as nothing is left in the tube to convey those undulations of matter which we know under

the name of electricity, no discharge takes place; in point of fact, it is possible to arrange two platinum wires, with their extremities only $\frac{1}{250}$ in. apart, enclosed in a glass tube from which the air has been practically all exhausted by means of a Sprengel, a Geryk, or other air pump capable of producing a very high vacuum, so that no spark or appreciable discharge shall take place between them, while at the same time two rods, separated to a much greater sparking distance, and connected to the two former, will allow electricity to discharge itself freely between them in the air. Between these two points—viz., the production of a long and, comparatively speaking, feeble violaceous discharge in a partial vacuum, and the absolute impossibility of producing a discharge of any kind across a perfect vacuum, several peculiar effects are observable. The length of spark with a given electro-motive force increases inversely as the pressure between 11 in. of mercury and 30 in. (which is equal to the pressure of one atmosphere). At lower pressures a greater difference of potential must be used to produce a spark. When we come to an exhaustion equal to about $\frac{1}{1000000}$ of an atmosphere, the E.M.F. required to produce a discharge is very nearly half as much again as that required under ordinary atmospheric conditions.

§ 7. When such high vacua are reached, the electric discharge produces little or no visible light; but its presence is capable of being rendered evident by its power of causing certain bodies to glow with light, or 'fluoresce.' If the apparatus take the form of a glass

tube or bulb[1] (see fig. 2) with a platinum electrode at each end, as the glass itself is a body capable of 'fluorescing,' the interior of the bulb is seen to glow with a soft yellowish light, which may vary according to the degree of vacuum in the tube and the voltage of the current, passing from a pale apple-green to a dis-

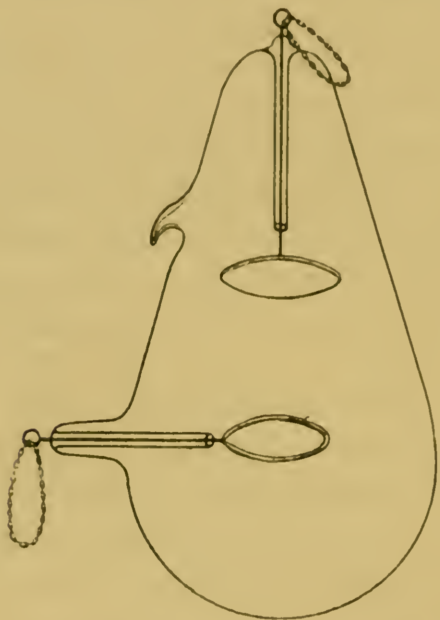

FIG. 2.—CROOKES' TUBE (OLD FORM).

tinct canary-yellow colour. In any case, however, the light is so feeble as to be barely perceptible in daylight.

§ 8. Whatever may be the nature of the vibration

[1] Usually designated a 'Crookes' tube,' from the name of the scientist who first investigated the properties of these high vacua.

or undulation set up in the highly rarefied medium contained in the exhausted tube, what is certain is, that it possesses properties which partake at once of those of light and of electricity, while differing in many respects from both. One of the properties common to electricity is that of setting up inductive effects in surrounding media, and of attracting light bodies placed in the vicinity of the exhausted tube wherein the discharge is taking place. These effects may be easily shown if a tube

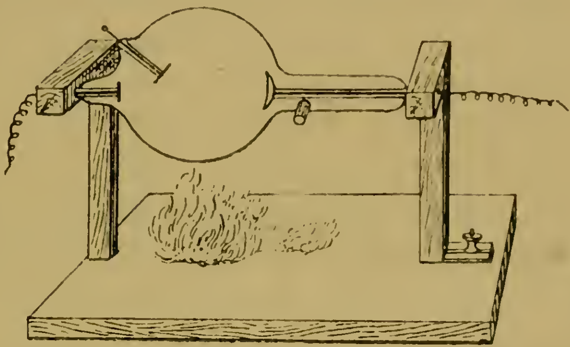

FIG. 3.—TUBE ON STAND, SHOWING ATTRACTION OF COTTON WOOL.

be arranged as in the annexed fig. 3, and underneath it, at a distance of about 6 in., a Franklin plate, or two sheets of writing-paper superimposed, or even some tufts of cotton wool, be placed. If now a discharge be set up in the tube, either by means of a coil giving a suitable length of spark, or else (and preferably) from the outer coatings of the Leyden jars belonging to a Wimshurst machine, with the discharging balls arranged at a convenient 'striking' [1] distance, the tufts of cotton

[1] For ordinary tubes this distance will be about 3 in.

wool will be seen to be attracted, the two sheets of paper will be found to be each charged in opposite senses and therefore to adhere strongly to one another, or, finally, the Franklin plate will be found to have taken up a charge. Similar to electricity also, these undulations or vibrations possess the power of causing certain bodies to fluoresce or give out light, notably certain salts containing tungsten, platinum, uranium, barium, calcium, &c. They differ, however, from the ordinary visible electric discharge in their effects, inasmuch that whereas in order to set up fluorescence in the latter case the fluorescent body must not be shielded from the source of undulations by any body which is opaque to ordinary light (such as wood, leather, ebonite, &c.), in the former many so-called opaque bodies, such as those already enumerated, are virtually transparent to these undulations, and allow the fluorescent effect to take place through them with the greatest facility. On the other hand, some bodies which are transparent to ordinary lights (such as glass and certain crystals) are extremely opaque to these undulations. The point of resemblance between these undulations and light, in addition to that of being easily transformed into visible light, as above shown, consists in their very marked action on the sensitive photographic film, such as is employed for use in ordinary white light. Here, again, the peculiarity evinced by these undulations of being able to penetrate blocks of wood, brick, sheets of leather, ebonite, stout cardboard, flesh, &c., as though they were transparent bodies, while they are unable to pass

through thin metal, glass, and some other visually transparent substances, shows itself in a most marked manner.

§ 9. The first one who called attention to the peculiarity of these undulations set up by electrical discharges in very high vacua was Professor Lenard, a Hungarian; closely following him came Conrad W. Röntgen, professor at the University of Würzburg, Bavaria, who showed that *bone* was much less transparent to these undulations than *flesh* while more transparent than metal, and that hence practical application was possible in the way of locating, by means of this new method of photography, the presence of shot, of needles, and other extraneous bodies, &c., in the human subject; also of abnormal growths, or ankylosis of the bones; or in the case of breakage, and subsequent surgical treatment, of the greater or lesser degree of success attained in the setting of bones, &c.

§ 10. The power of being able thus to see through the flesh, by means of the undulations which, passing through it, are allowed to impinge on the surface of a screen superficially coated with one of the above-named fluorescent bodies, more especially barium-platinocyanide or calcium tungstate, affords a ready means of localising the presence of abnormalities in the human organism, &c., without the trouble and loss of time entailed by taking a radiograph. It has been found that as the rapidity with which the discharges take place across the vacuum increases, and the electro-motive force supplying the current rises, so the penetrative power of these

undulations (now known as Röntgen rays, X rays, or cathode rays) varies, so that some bodies which are opaque to the rays taking their origin from a current of 150,000 volts pressure, become transparent to those originating under a pressure of 300,000 volts or more. Mr. T. C. Porter has shown that rays to which the flesh is actually more opaque than the bone may be obtained by cooling the tube to a very low temperature by means of solid carbonic acid and ether.[1] Another very peculiar effect of these undulations, or rays, is that of increasing the electrical conductivity of many insulating bodies, notably paraffin and ebonite, when subjected to their influence. The rate and amplitude of discharge or oscillations, whether obtained from Leyden jars or from induction coils, can be altered to almost any desired extent by the employment of condensers of greater or lesser capacity, or by the insertion of 'choking coils' (or other similar devices), which, by giving the 'discharge current' more electro-magnetic work to do, act as a 'drag,' or 'inertia.'[2] The following is an extract from 'Nature' (vol. lv. p. 30) bearing on this peculiar effect of interruption or resistances in the circuit:

'Mr. Porter appears to have obtained very good results by introducing several spark gaps and induction spirals into the circuit

---

[1] To these waves the name of X_2, X_3, &c., rays have been given.

[2] It must be borne in mind that, with the very rapid undulations which take place with the Leyden jar or Tesla transformer, it is of no advantage to introduce *iron* into the coils, since, as the waves succeed each other in opposite directions so rapidly, the iron is incapable of taking up the rhythmical measure.

between the two electrodes of the machine and those of the tube. In one of his experiments a Wimshurst with two 15 in. plates was employed to excite the tube. Several different arrangements were tried; one of the best may be described as follows: Starting from the negative electrode of the machine, we have first a ½ in. air gap, then a helix of wire followed by a ¼ in. air gap, followed by the cathode of the tube. Then starting from the anode of the tube, there occurs a ½ in. air gap followed by a helix of wire, between which and the positive electrode is another ¼ in. air gap. This arrangement gives a series of rapid and brilliant flashes in the tube. The human backbone can be seen on the screen through 8½ in. of brick wall.'

CHAPTER III

THE INDUCTION COIL

§ 11. Having thus glanced at the successive steps which have led up to a knowledge of the peculiar properties and useful applications of the electric waves set up in high vacua, we can pass on to the consideration of the practical portion of our subject, and to a study of those pieces of apparatus which are necessary to attain the desired results. The essentials for the production of radiographic pictures are, firstly, a source of electricity; secondly, a means of raising the E.M.F. of the electricity set up by the source, and also of increasing or decreasing the frequency of the undulations or 'discharge waves'; thirdly, some form of vessel or tube in which a vacuum of the desired degree of rarefaction has been or can be produced; fourthly, a stand or other means of supporting and maintaining the aforesaid vacuum tube in any desired position—this stand being so constructed that the two opposite ends of the tube (the anode and cathode respectively) may always be so well insulated that there shall be no tendency for the discharge to take place *outside* the

tube along any portion of the stand rather than traverse the high vacuum which obtains within the tube; fifthly, a sensitised film or plate, on which the image of the shadow cast by the rays traversing bodies more or less pervious to them is received and recorded. Along with the 'sensitive film' we include the necessary protecting envelope, which, although impervious to ordinary light, is transparent to these X rays. Under this head also must be classed the appliances and chemicals necessary for the development, for the fixation, and for the subsequent printing and mounting of the pictures produced. As, however, these are common to ordinary photography, no special or detailed description will be given of them, except in those points in which it may be advisable to vary somewhat the practice followed in obtaining an ordinary photographic picture. Sixthly, and lastly, a fluorescent screen which, on being placed between the tube emitting the rays, the object to be examined and the eye, by converting the invisible undulations into visible light rays, enables the operator to differentiate the texture and the components of many bodies subjected to the action of the X rays. This screen is also useful in some cases to shorten the time of exposure required by the sensitive plate to secure an image.

§ 12. Although there is no doubt that almost any generator capable of supplying electricity in sufficient quantity, and at a sufficient potential, could be used for the production of X rays, and consequently of radiographic effects, yet in practice only three instruments have found favour. These are the induction coil, the

Wimshurst machine,[1] and the Tesla transformer. We will consider these in the following pages, giving sufficiently explicit directions to enable the intelligent amateur to construct either of the pieces of apparatus with a fair certainty of success.

§ 13. The induction coil for this purpose should be capable of giving a clean and continuous discharge or spark across at least 3 in. in air. Although it is possible by using a small tube, with electrodes rather near one another, to take a picture of certain thin bodies with coils giving as little as 2 in. of spark, yet the exposure is long, and the detail never very good. On the other hand, for all ordinary purposes, it is rarely necessary to exceed the power given by a 6 in. spark; and this will enable the operator to distinguish on the screen the beating of the heart, and to take a photograph through the chest or abdomen in twenty or thirty minutes, while pictures of the hands, feet, &c., can be obtained in from one to two and a half minutes. Reckoning the E.M.F. required to produce a 1 in. spark in air at 50,000 volts, this means that the potential employed should not be less than 150,000 volts, and may conveniently rise to 300,000 volts. In purchasing such a coil, it will be well to notice the following points: firstly, that the coil be capable of giving really a measured 3 in. or 6 in. spark, as the case may be, between two wires connected to the secondary terminals; secondly, that the battery power required

[1] The Holtz machine has also been used with great success in America, by Dr. Monell; a section has been dedicated to a description of his machine and its results in this book, q.v.

should not be excessive. It should not exceed six cells, quart size, of Bunsen or Groves, or six accumulators, in the case of the 3 in. spark coil, or eight such cells in the case of the 6 in. spark coil. The wire of the primary should be sufficiently stout to admit of its carrying the full current capable of being given by the above-mentioned batteries (and which will probably not be less than 12 ampères) without heating. The condenser should be of sufficient capacity to keep down any injurious sparking between the platinum points of the contact breaker, and the platinums themselves should be heavy enough to carry all the current passing, without any tendency to welding together through heating. These large coils should be provided with a commutator, in order to be able to rapidly change the direction of, or cut off, the current at will. It will also be found convenient to have the battery terminals marked + and −, with corresponding marks to show the direction of the current through the commutator; and lastly, a mark denoting which is the + terminal of the secondary wire, when the commutator and the positive terminal of the primary wire are in a certain position with regard to one another. This can easily be effected by marking the primary terminal which it is intended to couple with the positive pole of battery with a +, and then, having placed the commutator so that the bars touch a given spring, to mark one touching bar and spring with a +. This done, the positive end of the secondary coil is ascertained by means of a piece of pole-testing paper, and this also marked by a +. Provided the crosses are then always coupled up as just

marked, the polarity of the two secondary wires will always be the same in all future experiments.

§ 14. The following general instructions for the construction of coils specially intended for X-ray work will enable anyone gifted with a fair amount of pains-taking patience, and a little mechanical skill, to build a coil capable of giving a 3 in. or a 6 in. spark, according to the dimensions decided upon. In order to avoid useless repetition, a table of the dimensions of the various parts is given first; then follows a description of the mode of doing the actual work of construction. The reader is here warned that he must not suppose that there is no other way of building a coil capable of giving good results, or even that an equal length of spark may not be obtained with a less amount of wire, &c.; but simply that if he carefully carries out the specifications given, especially with regard to perfect insulation and exact testing of each section of the secondary, he will not fail of obtaining the desired results.

Dimensions of Parts for a 3 in. Spark Coil

Iron bundle of No. 20 B.W.G. annealed iron wire, $1\frac{1}{4}$ in. diameter, 13 in. long.

Primary wire: four layers of No. 14 double silk-covered copper wire, about $4\frac{1}{4}$ lbs.

Ebonite tube over primary, 12 in. long, 2 in. inside diameter, $2\frac{1}{2}$ in. outside.

Two ebonite heads, 5 in. square, $\frac{1}{2}$ in. thick.

Seven vulcanised fibre circlets (for sections), $4\frac{1}{2}$ in. diameter, $\frac{1}{8}$ in. thick, $2\frac{1}{2}$ in. central aperture.

Four lbs. No. 35 double silk-covered wire.

Platinum tip contact breaker, height from base to centre of iron

hammer $2\frac{1}{2}$ in.; size of iron head of hammer $\frac{3}{4}$ in. diameter × $\frac{3}{4}$ in. long.

Base (fitted with false bottom to contain condenser), 18 in. long × 9 in. wide × $2\frac{3}{4}$ in. deep.

Condenser, 144 sheets of tinfoil, size 12 in. × 6 in., interleaved with 144 sheets of paraffined paper, 8 in. × 13 in.

Dimensions of Parts for a 6 in. Spark Coil

Iron bundle of No. 18 B.W.G. annealed iron wire, $1\frac{1}{2}$ in. diameter 15 in. long.

Primary wire: four layers of No. 14 double silk-covered copper wire, about 5 lbs.

Ebonite tube over primary, 14 in. long, $2\frac{1}{4}$ in. inside diameter, $2\frac{3}{4}$ in. outside diameter.

Ebonite heads, 6 in. square, $\frac{3}{4}$ in. thick.

Seven vulcanised fibre circlets, $5\frac{1}{4}$ in. diameter, $\frac{1}{8}$ in. thick, with $2\frac{3}{4}$ in. central hole.

Seven lbs. No. 36 double silk-covered copper wire.

Platinum tip contact breaker, height from base to centre of hammer 3 in.; size of hammer head, 1 in. diameter, 1 in. long.

Base (fitted with false bottom to contain condenser), 20 in. long × 10 in. wide × $3\frac{1}{2}$ in. deep.

Condenser, 144 sheets of tinfoil, size 12 in. × 6 in., interleaved with 144 sheets of paraffined paper, 8 in. × 13 in.

§ 15. In order to produce a successful coil, the greatest care is required in order to ensure perfect insulation. The pressure or 'tension' set up in the secondary wire of these coils (amounting to no less than 150,000 volts in the 3 in. spark size, and to 300,000 in the 6 in. spark size) is so enormous that there is always a tendency for the current to leak off at some undesirable place; and if this once takes place, the evil rapidly increases, and the insulation of the coil breaks down. All

our efforts, therefore, must be directed to rendering the insulation between the primary and secondary wires, as also between the different layers or sections of the secondary wire itself, as perfect as possible, consistent with not introducing so much space between the inducing primary and the induced secondary as would seriously lessen the inductive effect of the former. But it must not be imagined that the task is superlatively difficult, or calls for the use of any expensive or refined apparatus; on the contrary, as Mr. F. C. Allsop [1] well puts it:

'The main requirements necessary for success are patience and a determination to construct each part thoroughly. Never leave one portion until quite satisfied that every precaution has been taken to render it as perfect as it is in your power to make it. Remember that even one little point passed over in a slovenly manner may be the cause of a complete failure, and that it is an easy matter to alter certain parts during construction, while, when finished, it is often impossible to do so without pulling the whole coil to pieces.'

§ 16. The first operation consists in making the soft iron core for the primary. A sufficiency of the best annealed charcoal iron wire, of the gauge indicated in the table, should be procured, and, if not already straight, should be straightened out by pulling between three nails set in a board, and cut off into lengths according to the table. The bundle should be made into a cylindrical form of the diameter indicated, and the best way of doing this is to make a brown-paper tube, like a rocket-case, of the size of the desired bundle, and insert the

[1] *Induction Coils and Coil-making.*

straightened iron wire into this, until a hard bundle has been formed. One end of this should be allowed to project considerably beyond the tube, and should be wrapped spirally from end to end with rather wide tape dipped in shellac varnish. The bundle should be withdrawn from the tube as the wrapping goes on, the tape being pulled very tightly so as to ensure the bundle coming out firm and cylindrical. When the bundle has been entirely drawn out, the finishing end of the tape should be stitched to the layer below and cut off flush. When the varnish is dry it will be well, in order to prevent the wire rusting at any future time, to boil the entire bundle in melted paraffin wax. It should then be stood up on end to drain and cool.

§ 17. The next step is to wind the core with the primary wire. This may be done in either of the two following manners: first, *by hand*, in which case about 8 in. of the primary wire are allowed to stand out free, for after-connection to the terminals and contact breaker of coil, and firmly tied down by means of silk twist to the core (this to prevent the wire untwisting and flying back) at a distance of about $\frac{1}{2}$ in. from the starting extremity of core. The wire can now be wound on as closely, evenly, and tightly as possible to within $\frac{1}{2}$ in. of the other extremity. This should likewise be tied down to prevent slipping, and the winding continued over this, taking care that the wire lies between the channels of the under layer. In this manner all four layers are to be wound on, the terminating end being likewise carefully and strongly tied down with silk twist as before,

when, having cut off the terminating end of wire so as to leave another 8 in. piece for future connection, the whole may be bound with a spiral tape wrapping as was recommended for the bare coil. Or, secondly, the core may be wound on a *winder*, which consists of a flat board, rather longer than the length of a core, on which are erected two standards facing one another, having opposite holes at their upper extremities. The core is placed between these two uprights, and supported in that position by having a longish French nail passed through the hole in one standard into the centre of the core at one end, the opposite end being supported by a cranked arm or handle, pointed and squared at one extremity, which, passing through the hole in the opposite standard, is also driven into the iron wires at the centre of the core.

By rotating this handle (one end of the wire having been previously tied down to the core) it will be easy to wind the primary wire very evenly and regularly. The same precautions of course must be taken as to tying down the wire and finishing off with tape.

In whichever way the winding may have been effected, the result should be a perfectly even and cylindrical rod, with the two projecting ends of wire at one extremity. The finished and wound cores should now be either heavily shellac varnished, or else immersed in hot paraffin wax until all bubbles of air are extricated.

§ 18. The next step is to fit the ebonite tube over the primary; and owing to the uncertainty in the evenness of winding, and consequently the exact resulting

diameter of the wound core, it will be advisable to leave the purchase of the ebonite tube until the primary has been finished. The bore of the tube should just allow the primary wound core to slip in easily, without any waste space, the outside dimensions being those given in the table.

§ 19. When a suitable tube has been chosen and cut off to the right length, it must be placed between the centres of a lathe, and a male screw thread cut for about $\frac{1}{2}$ in. in, at each extremity, to fit into a corresponding female screw, which must be cut in the centre of the ebonite heads, which are to form the cheeks of the coil. The vulcanised fibre circlets may now be adjusted, turned up to exact size, so that they just slip over the ebonite tube, without play, the heads of course being removed for this purpose. One hole in each head should now be drilled and tapped to take the shank of the secondary terminal, and in the centre of the opposite edge it will be well now to drill similar holes to receive the screws that are to hold the coil down to its base. (These latter screws will affect the working of the coil less injuriously if they are of ebonite, vulcanised fibre, or ivory.)

§ 20. The winding of the secondary can now be proceeded with. For the 3 in. coil it will not be necessary to use other sections besides those furnished by the vulcanised fibre circlets. A sufficient quantity of long strips of good demy paper, carefully paraffined by running through a bath of melted paraffin wax, should be prepared. These strips should, for the 3 in. coil, be $1\frac{1}{16}$ in. wide, and in all cases should be long enough to

go once round the layer of wire, with a little to spare to lap over; hence the shorter ones at the beginning will be about 9 in. long, while those for the top layers will require to be 18 in. long. The operator will then put together the heads, ebonite tube, and vulcanised fibre washers, in the following manner. He will begin by drilling a hole, a little larger than the No. 36 wire he is going to use, at $\frac{1}{8}$ in. from the edge, through the periphery of four of the vulcanised fibre discs, which will hereafter be distinguished as discs 1, 3, 5, 7. He will in like manner drill a hole within about $\frac{1}{16}$ in. of the inner edge (close to where the vulcanised fibre disc slips on the ebonite tube) of the other three discs, which must be distinguished as 2, 4, and 6. Having removed one of the heads off the tube, he will slip on the fibre washers in numerical order, 1, 2, 3, 4, 5, 6, 7, and finally screw on the head at the opposite side, taking care, of course, that the holes that are to take the terminals and the holding-down screws respectively are in a line with each other. The tube is now to be mounted between the standards of a winder as already described at § 17, a wooden mandrel packed with paper rolled round it being sufficient to carry the supporting pin at one end and the cranked handle at the other. Or the mandrel may take the form of an iron rod, tapped and screwed at each end to allow nuts to run on, which serve to clinch up and hold the tube with its heads, &c., in place. Things being thus arranged, the vulcanised fibre disc No. 1 is pushed up against the cheek nearest to it, care being taken that the little hole at its top

edge is in a line with the hole in the edge of the head, which will afterwards receive the terminal. One turn of the paraffined 1$\frac{1}{16}$ in. paper strip is now rolled round the ebonite tube close to washer No. 1. Washer No. 2 is now brought close up to the edge of the paper layer, care being taken that *its* hole (which is near the centre) should also be in a line with the terminal screw hole. The vulcanised fibre washer No. 2 can be, if necessary, fastened into this position by running a little Prout's

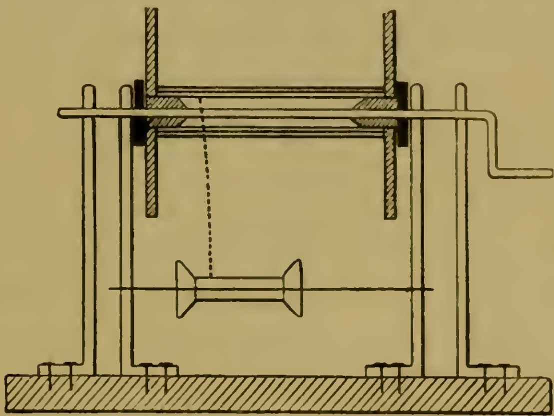

Fig. 4.—Simple Winder.

elastic glue or Chatterton's compound round the seam between the ebonite tube and the washer, by the aid of a hot piece of wire or small soldering iron, gently heated. When this has set the operator passes about 1 ft. of the No. 36 silk-covered wire (which ought to be in one continuous length on each reel to facilitate testing) through the hole in disc No. 2, causing the wire to enter the hole at the No. 1 side and to come out at the No. 3 side. The free foot or so of wire may be coiled

round the space between discs 2 and 3, and tied down, so as not to get in the way. The reel or bobbin containing the wire having been slung between the standards on the lower support as shown at fig. 4, the wire can be wound on the space between washers 2 and 1, until the first layer is filled up. The handle or crank *must* for this section be turned *clockwise* for the whole number of coils laid on. The greatest care must be taken, in laying on the coils, that no kinks, breaks, or even irregularity of winding occur, since the two former will prevent the coil from working, and the latter will greatly lower its efficiency. When one layer of wire has been laid on from disc to disc, it should be paraffined by being basted in hot paraffin wax with a hot spoon or small ladle. (For the larger coil the wire as it passes from the bobbin on which it is sold may be run directly through a little trough of paraffin wax, kept at a melting point by the aid of a spirit lamp, as shown at fig. 5.)

It will be well not to go quite up to the washer No. 1, but to stop winding within about $\frac{1}{8}$ in. of this washer. The layer having been paraffined by either of the plans suggested, a strip of the paraffined paper, sufficient to go once round and lap over for about $\frac{1}{2}$ in., is slightly warmed so as to soften the paraffin, and bound tightly over the first layer of wire, care being taken to let the end of the wire which is still attached to the lower bobbin follow the fold of the paper and come out near washer No. 1 from under the paper at about $\frac{1}{8}$ in. from the washer. Layer No. 2 is now wound on in a precisely

similar manner, ending at about $\frac{1}{8}$ in. from washer No. 2, when this second layer must be basted with paraffin wax in either of the ways before suggested, and wrapped as previously described with a strip of paraffin paper. In like manner each succeeding layer of wire is laid on until the full proportion of wire, say $\frac{2}{3}$ lb., has been coiled on. This will take from 40 to 48 layers per section, according to the neatness of the winding. At

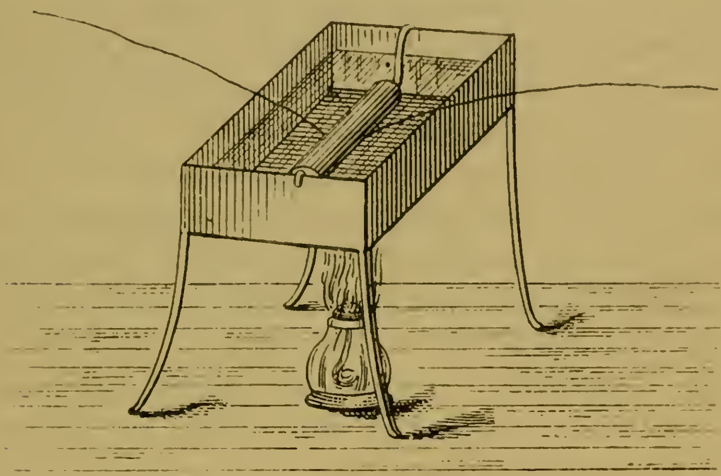

FIG. 5.—BASTING WIRE IN PARAFFIN WAX.

this point the wire can be cut off from the reel, leaving a free end about 1 ft. long, which (by unscrewing a trifle the head nearer washer No 1) can be passed through the holes in the edge of the washer, rolled round a knitting needle so as to form a tight spiral, and left projecting between the washer and the head (which is then to be screwed up in its place), ready for attachment to the terminal.

§ 21. The next step is to wind section 2. To do this the free end of the wire, of which we had passed about 1 ft. through the hole in the washer No. 2, is untied from round the bobbin, about $\frac{1}{2}$ in. of its extremity bared of its covering, and soldered to the beginning wire of another bobbin of No. 36 wire of sufficient size to fill up the section (about $\frac{2}{3}$ lb.). The joint must be carefully insulated. The space between washers No. 2 and No. 3 is now dressed with one turn of the $1\frac{1}{16}$ in. paraffined paper strip, as described in the last section, and the wire wound on precisely as described, with all the precautions of basting with paraffin, of perfect continuity, of insulating each layer with a turn of paraffin paper, &c., but with this one important difference—viz., that in winding on the wire the handle which causes the mandrel to turn *must now be rotated counter-clockwise*. If this were not done, the two layers 1 and 2 would be wound in opposite directions, the result of which would be that the current in the one section would exactly annul the current in the other.

Section No. 2 having thus been filled in, a 3 in. bight of the wire is passed through the top hole of washer No. 3, for future attachment to the termination of section No. 3. In precisely similar manner, but starting with the inside or lower hole of washer No. 4, section No. 3 is to be wound, the handle being *rotated clockwise* for this section, and the ending wire (which will be at the surface) neatly soldered to the little bight which has been passed through the hole in the edge of washer No. 3. This join should be carefully insulated with

Prout's elastic or Chatterton's compound, and neatly tucked under another turn of paraffined paper. Again we make a join of a fresh bobbin of wire to the inner wire projecting through washer No. 4, and with all the previously described precautions we wind in the coils required to fill section No. 4, which requires the handle to be turned *counter-clockwise*. This will bring the ire to the top hole in washer No. 5, through which we pass a 3 in. end, and cut off. We proceed to wind section No. 5 by passing a short end of the wire through washer No. 6, and fill in section No. 5 by winding *clockwise* and then joining the termination, as before described, to the wire projecting through the top hole of washer No. 5. Lastly, we solder the end of the last $\frac{2}{3}$ of a lb. of wire to the end of the wire projecting through the lower hole in washer No. 6, and, having insulated it carefully, proceed to fill in, as before, section No. 6, the termination wire of which is passed through the top hole of washer No. 7, curled into a tight spiral round a knitting needle, and left ready for attachment to the terminal which will afterwards be placed on the head near washer No. 7. It must be carefully borne in mind that, in order to ensure the wire being wound continuously in one direction, the handle must be rotated *clockwise* for sections 1, 3, and 5, and *counter-clockwise* for sections 2, 4, and 6. When the whole has thus been satisfactorily wound, and tested for continuity, the completed secondary should be well basted with melted paraffin wax, and the surface smoothed off with a warm iron spatula, until it stands at the same level as the

washers. The position of the *ends* of the wire, where they pass through the section division, is shown at fig. 6, where for clearness an inclined line takes the place of a complete coil of wire.

§ 22. If the operator decides to make the 6 in. spark coil, he will be more likely to succeed if, instead of building up the coil in seven sections only, of about 1⅝ in. space each, he fills in each of these spaces with twelve

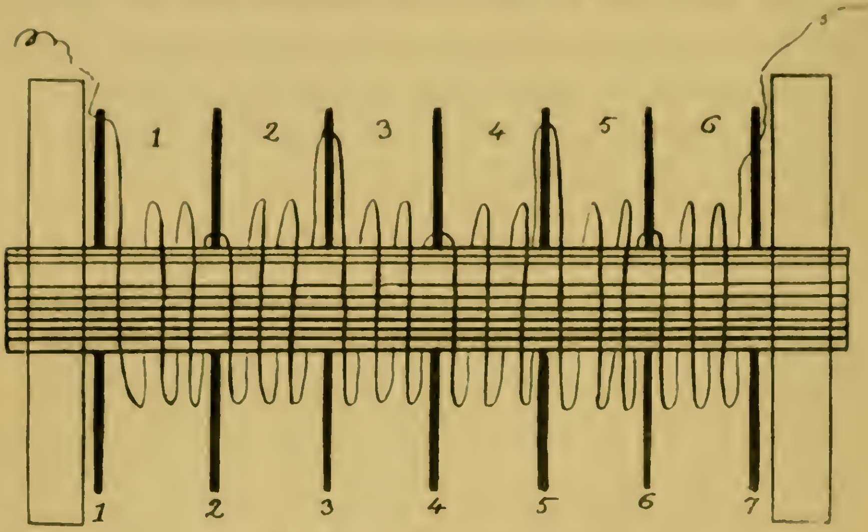

Fig. 6.—Mode of Winding Sections.

sections wound in between cheeks of paraffined paper, the same size as the vulcanised fibre washers, each paper section having about ⅛ in. thick of wire coiled in it. The best way to coil these sections is to procure a metal collar, a trifle larger in diameter than the ebonite tube of the coil, and of the thickness that it is intended the sections should be. A spindle passes through the centre of this collar, and is supported on upright standards similar to

those of the winder described at § 17. The spindle carries upon it two $\frac{1}{16}$ in. brass or zinc discs, carefully faced up, which are held in their place on either side of the collar by means of back nuts. These discs should of course be somewhat larger than the diameter of the completed sections. The collar should be slightly curved on one side, to allow the wire to slip off easily, after winding on; and it must be borne in mind that even on the side at which it is smallest it still must exceed the diameter of the ebonite tube by $\frac{1}{64}$ in. or thereabouts, or else the coiled section will not easily be got to slip in its place over the ebonite tube. Fig. 7 is a sketch of this section winder, showing some of the separate parts, as well as the entire device mounted and at work; *a* represents the central spindle with the threaded portion and cranked handle, *b* the coned collar, *c* the discs, *d* the two nuts. At *e* we have this winder mounted, *f* being the melted paraffin bath, *g* the spirit lamp, and *h* the bobbin of wire mounted between standards. Things being thus arranged, rather more than $1\frac{1}{2}$ oz. of the wire off the bobbin *h* is coiled into the space between the two discs of the winder *c*. The wire, naturally, must be caused to pass through the bath of melted paraffin wax while the winding goes on. When the proper amount of wire has been wound in, the wire is cut from the bobbin, leaving 1 in. or so free for future attachment. A number of paper discs (about 144), with central hole the same size as in the vulcanised fibre washers, and of the same outside diameter, must have been previously prepared by soaking in melted

paraffin wax, and ironing off between sheets of blotting paper. The operator then removes the spindle from its standards, runs off the nut from the end farther from the

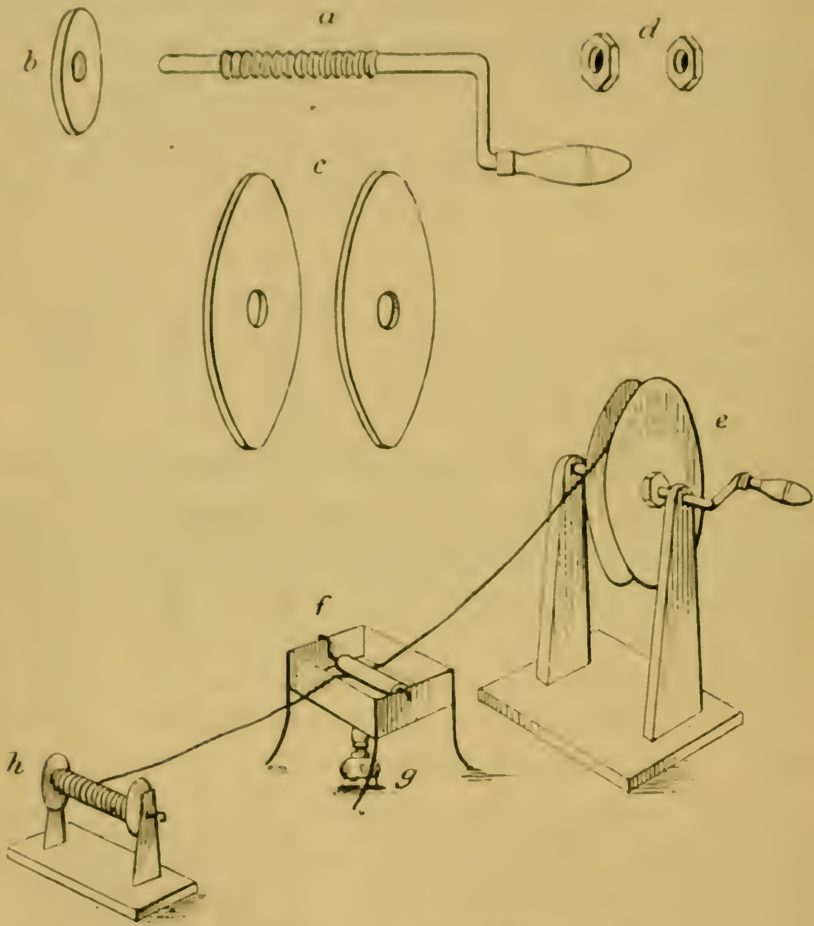

FIG. 7.—SECTION WINDER, SHOWING PARTS.

crank, and removes the disc. This latter may or may not bring with it the wound section of wire. If it is found to adhere to both discs, the application of a little

warmth will soften the paraffin sufficiently to allow the discs to be removed without disturbing the coils of wire. Having removed the upper disc, one of the paper circlets is placed over the cake of coiled wire, and the inner free end of wire having been drawn through the central hole, the circlet of papers is lightly ironed with a warm iron, so as to cause it to adhere to the coils of wire below. The central collar should, of course, have been removed by pushing on the coned side. The cake of coiled wire is now turned over, and a similar circlet of paper laid on and ironed over this side, the ending wire being allowed to lie on the outside of this latter circlet. The requisite number [1] of paper protected sections having been thus prepared, they must be joined up together in pairs. It is understood that in winding these sections the operator has always wound in the same direction—say, turned the handle *clockwise*. He will proceed to make up pairs of sections by placing two of the sections one on the other, with the *starting ends of the wire close to each other*, as shown at fig. 8. So important is this, that it will be well to mark the left-hand circlet of each separate section as it comes off the winder, and to remember that in joining up the pairs these marked circlets must face one another. The two inner wires are pulled through the central hole, bared, cleaned, and soldered together, cut off rather short, insulated with Prout's or Chatterton's, and tucked very carefully in between the two discs, which are then pressed together, and slipped on in their place on the ebonite tube. The whole number of sections can thus

[1] Seventy-two if the seven vulcanised fibre washers are retained.

be joined together in pairs as described, which method it will be noticed leaves the outer ends of the wires free. Ten of these paper sections are now slipped on the tube to make up the dozen, when a vulcanised fibre washer can be put in its place. A small hole is drilled through the outer edge of the fibre washer to allow of the passage

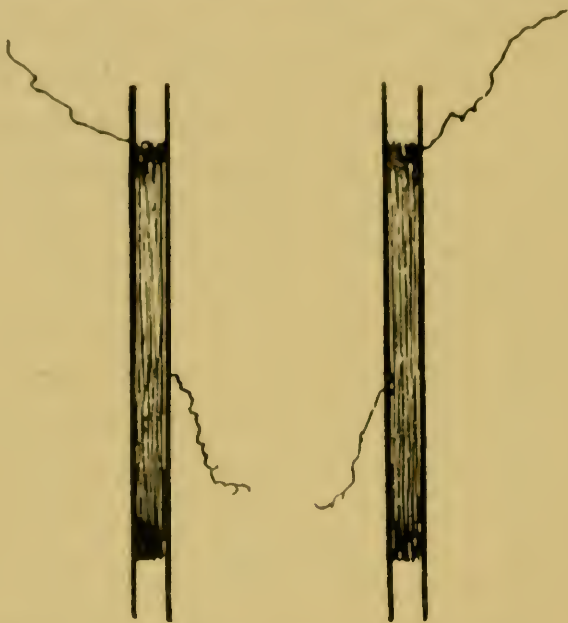

Fig. 8.—How Two Sections are Joined.

of the wire from the outside of the last paper section. Care should be taken in putting on the circlets that the free ends of the wires are all in a line with one another, and with the hole for terminal in the cheeks, and the top edge hole in the vulcanised fibre washers. In putting on these circlets, and before actually joining their outer wires together with solder, while they are

only bared and twisted, it will be well to put the primary and core in the tube, and try by means of a battery and contact breaker whether the spark increases with the increase of the number of sections, as it should do. Any mistake in connection and any defect in construction will soon become evident under this test, and the defective coil, or pair of coils, easily located, and replaced by sound ones.

The outer ends of the wires from each adjoining pair of sections (with the exception of the first and last, which of course go to their respective terminals) should now be twisted together, soldered, cut short and insulated, and finally tucked neatly between the paper of each pair of sections. The whole should then be thoroughly basted, as before directed, with hot paraffin wax, so as to form one compact cylinder, of the diameter of the vulcanised fibre washers.

§ 23. The operator will now proceed to the condenser. For this purpose he will choose the requisite number of sheets of good demy paper, and having cut them to the size specified in the table, he will examine them one by one, by holding between his eye and a strong light, and reject all such as show even the minutest puncture or imperfection. He will then run them, sheet by sheet, through a bath of hot melted paraffin wax, then hold up diagonally by one corner, to allow as much as possible of the wax to drip off at one corner, after which he will lay it across a line to cool. Should he have been successful in getting a pretty even coating, without ridges or superfluity of wax, nothing farther need be done to the sheets,

but any that are unduly thick, or are unevenly coated, should be placed between two sheets of white blotting paper, and passed over with a hot iron. The paper having been thus prepared, the sheets of tinfoil are now cut, also an equal number of strips of tinfoil, about 1 in. wide and 4 in. long. Two sheets of stout glass of the same size as the paraffined papers are now procured. One of these, after having been cleaned, is laid on the operating table, and a sheet of paraffined paper placed upon it. On this is laid a sheet of tinfoil, centrally, so as to leave an equal margin all round. On the tinfoil

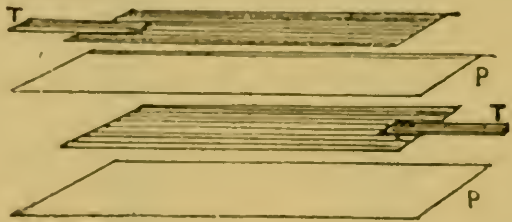

Fig. 9.—Condenser in Formation.

is placed one of the long strips, so arranged as to touch the tinfoil and to extend, on the right, for about a couple of inches beyond the paraffined paper. Another sheet of paraffined paper is now laid over this, on which a second sheet of tinfoil with *its* strip is also placed; but this time the strip must be placed to the left, and project 2 in. to the left. Proceeding in this manner—viz., paraffined paper—tinfoil—tinfoil strip to the right—paper—tinfoil—tinfoil strip to the left—a pile of paper, tinfoil sheets, and strips is built up, until the required number has been used up. A sheet or two of paraffined

paper are then added, over which the other glass plate is placed, and the whole bound round with a binding of tape. The disposition of the alternate sheets of paper and tinfoil is shown at fig. 9, and the appearance of the completed condenser at fig. 10. It will greatly improve the condenser if now the strips at either extremity be folded neatly over the upper glass, the condenser placed standing on a small square block of wood in a rather large dish, with a 4 lb. weight on its upper surface, and then put in a moderately warm oven, so as to melt out any excess of paraffin that there may be between the papers. When this has taken place the condenser may be withdrawn, and will be ready for use when cold.

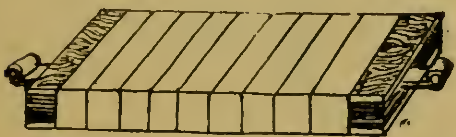

FIG. 10.—COMPLETED CONDENSER.

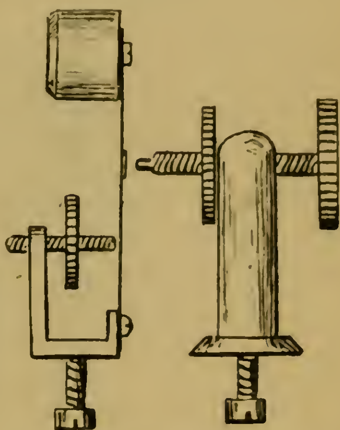

FIG. 11.—CONTACT-BREAKER.

§ 24. The contact breaker next claims attention. The great point to be aimed at, in order to produce a good long spark, is certainly a sufficiently long contact to enable the iron core to be magnetised to the full. For small coils, the ordinary hammer with spring and adjusting back nut as shown at fig. 11, in conjunction with a platinum-tipped screw on pillar, will be found

to give satisfaction; but with larger coils, either the Apps[1] form, of which a good illustration is given at fig. 12, or the 'Vril' will be found more satisfactory.

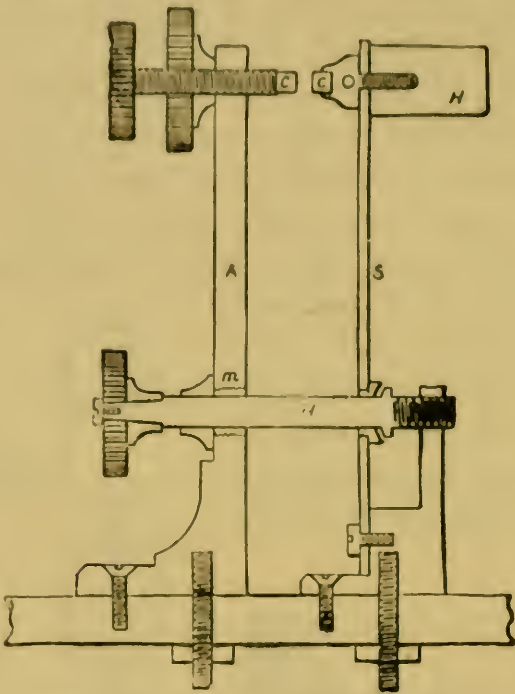

FIG. 12.—APPS' CONTACT-BREAKER.

at Fig. 13 is illustrated the 'Vril' contact breaker. It will be seen that there are two springs, one carrying

[1] It may be well to mention that, owing to the design and careful construction of the Apps contact breakers, they will work within the whole range of the applications to which the coil can be put. For instance, with a 10 in. spark Apps patented coil, the length of the spark can be regulated, without altering the battery or source of current, from $\frac{1}{2}$ in. to nearly 12 in. in less than one second. The quickness of the break is exactly adjusted to the best point. Very erroneous ideas were prevalent as to the nature of the break of current; and, to verify the practical limits of

the iron head, with a double-cranked extension, C, and the other bearing the platinum stud. This latter is the one through which the current passes from the plati-

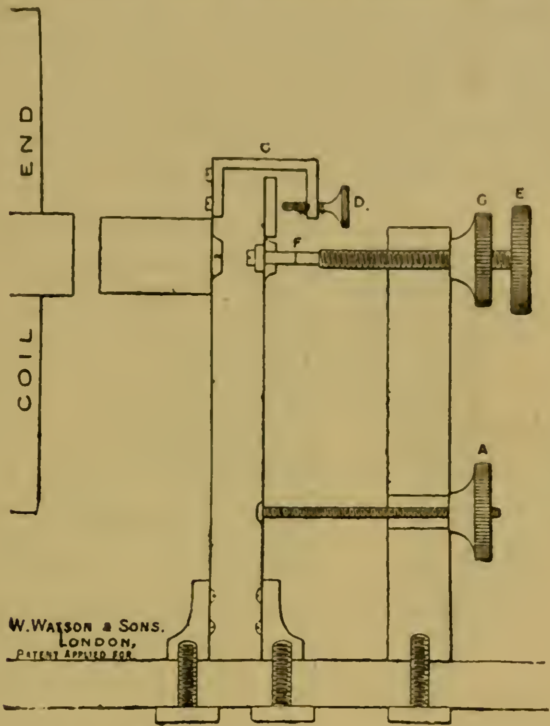

FIG. 13.—'VRIL' CONTACT-BREAKER.

num-tipped screw, at F, and it is not until the clapper head has travelled through a certain distance, which

utility, about twenty-five years ago Mr. Apps designed and constructed for the late Mr. H C. Baines, of Pembroke College, a wheel brake, with wedge and lever action, capable of breaking the primary circuit in any time from 1 second up to $\frac{1}{105}$ part of a second. The experiments were of an exhaustive character, and finally determined the degree of suddenness, which has been adopted in the contact breaker now made by Mr. Apps.

can be controlled to a nicety by the screw D, that contact is broken, by the piece C catching the top end of the contact spring, and pulling it away from F. Hence the coil core has plenty of time to get magnetised, and yet the break, when it does occur, is a clean and sharp one. A modification with double spring, which has given good results in the author's hands, is shown at fig. 14. This consists, virtually, of an Apps contact breaker with a second and rather stiff spring attached to the spring which carries the hammer head, and on the back of this second spring, opposite the contact screw, is placed the platinum contact. Whatever form of contact breaker be adopted, it is essential, in view of the large current which it has to transmit, as well as the self-induction spark which even the best condenser does not entirely do away with, that the platinum contacts themselves should be very heavy, and if possible surrounded by a considerable mass of good conducting metal. For this reason the platinum points themselves should be of not less than No. 14 B.W.G.; and in the case of the spring, if this is embedded in a boss of silver of rather over $\frac{1}{4}$ in. in diameter, the likelihood of the platinum points welding together is greatly diminished.

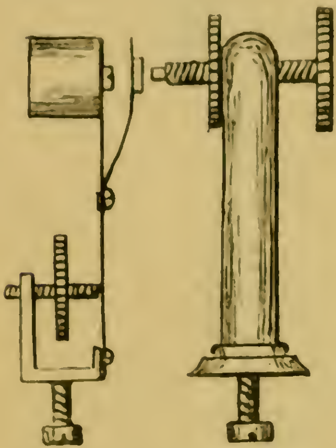

FIG. 14.—DOUBLE SPRING CONTACT-BREAKER.

§ 25. A necessary piece of apparatus in connection

with these large coils is the *commutator*, or current reverser, which enables us at will to cut off or reverse the direction of the current sent from the battery through the primary of the coil, and consequently to stop or reverse the direction of the main flow of the induced current in the secondary. A very usual form of commutator is shown at fig. 15. It consists of a cylinder

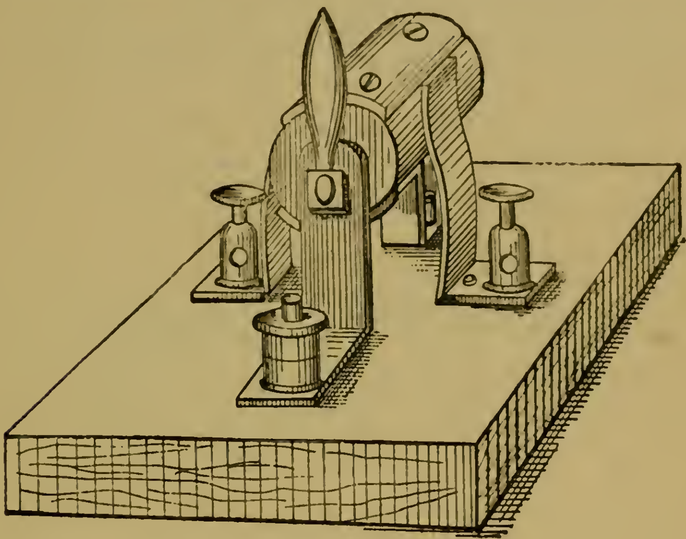

FIG. 15.—COMMUTATOR.

of ebonite, or other good insulator, mounted between two metal standards which can be placed in circuit with the battery. Each end of the cylinder is fitted with a metal head of the same diameter, and a tongue of metal in connection with these heads is let in at opposite sides of the ebonite cylinder, reaching not quite to the opposite head. In other words, each head has a tongue bent at right angles to itself, embedded in the periphery of the

cylinder at opposite diameters. Two springs are fastened on the base, in such a position as to press against the cheeks of the cylinder. A small handle or thumb nut is attached to the shaft on the outside of one of the standards, in order to enable the operator to rotate the cylinder, and thus bring either the metal strips or the plain ebonite in contact with the springs. It must be borne in mind that the spindle or shaft which supports the ebonite roller must be in two separate pieces, *not in contact with one another*, but in good electrical contact with their respective heads. It will be evident that if the two poles of a battery are connected to the terminals in connection with the trunnions, while the outer circuit is connected to the binding screws attached to the lateral springs, no current will pass so long as the cylinder stands as shown in the cut. If, however, the handle be turned to the right, the upper brass cheek will be brought into contact with the right-hand brass spring, while the lower brass cheek will be brought into contact with the left-hand spring, the current flowing from the front terminal will pass along the right cheek, down the right-hand spring to the outer circuit, returning by the left-hand terminal through the left-hand spring, and left-hand cheek down the farther standard and terminal (which is not visible in our cut). If the handle is turned to the left, so that the upper cheek touches the left-hand spring, the current will flow in the opposite direction in the outer circuit. This form of current reverser serves at once, therefore, as a two-way switch and as an interrupter or rheotome.

§ 26. The base or stand, of the dimensions already

given, should be made of well-seasoned mahogany, carefully morticed together, and should not be less than $\frac{1}{2}$ in. thick. It should be well polished, as this renders it a better insulator. The space in the bottom should be sufficiently deep to take the condenser ; and four wooden blocks should be glued into the inside corners, on which the thin board which forms the false bottom may rest, and be screwed. A sketch of the inside of this base and the covering which forms the false bottom is shown at fig. 16.

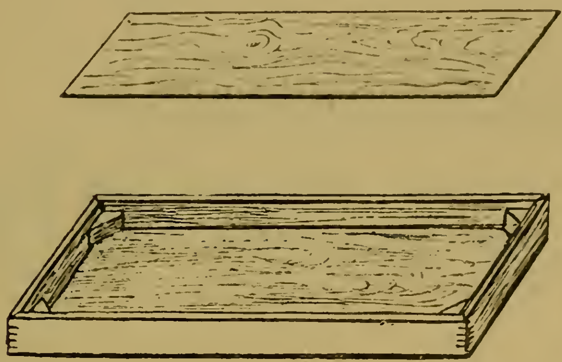

Fig. 16.—False Bottom in Base for Coil.

§ 27. The relative positions of the coil parts and condenser on and in the base are shown sectionally in our fig. 17. To avoid confusion the two battery terminals are placed in a line one with the other, instead of one behind the other ; also the commutator is shown farther from the contact-breaker than is really the case, it is generally placed at one side of it. Before finally mounting the coil, when the heads have been screwed in their place, the secondary terminals put in, and the two ends of the secondary wire connected thereto, the entire

coil should be enveloped with one turn of thin sheet ebonite, the edges of which just lap below, and holes having been made at suitable distance along the edges with a hot wire, the roll can be drawn tight by lacing together through these holes with a piece of strong silk twist. This forms a good insulating covering for the whole, and one which is easily removed if it should be desirable at any time to examine the secondary.

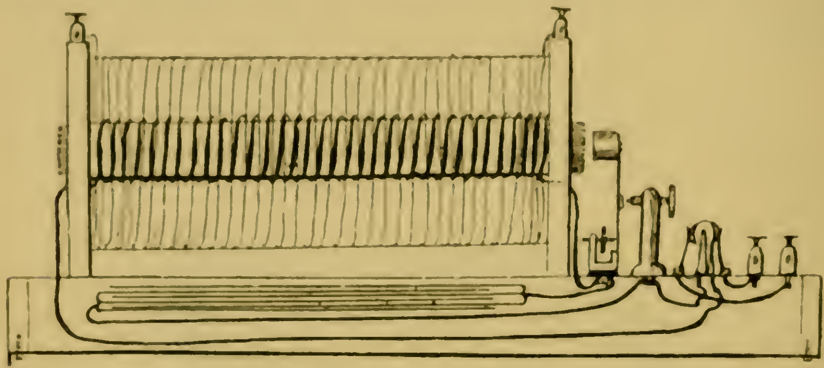

FIG. 17.—RELATIVE POSITIONS OF COIL AND CONDENSER.

§ 28. There is one point to which it is desirable to draw the reader's attention, and that is, that some brands of paraffin contain free acid, which not only lowers the insulating property, but is very apt to rot the copper wire. To remedy this state of things it will be wise, as suggested by Mr. Reynolds in the 'English Mechanic' for September 3, 1897, to roast some powdered chalk to dull redness, and add this to the melted paraffin wax, in the proportion of about 1 oz. to the lb. The clear wax should then be strained off from the chalk. This will effectually neutralise any free acid.

CHAPTER IV

ON THE CHOICE OF SOURCE OF CURRENT

§ 29. The sources from which to obtain the current necessary to actuate the coil next demand attention. These are usually: first, batteries; secondly, accumulators; thirdly, dynamos giving either direct or alternating current. Of batteries there is none at once so trustworthy and convenient as the chromic acid cell, with single zinc and two carbon plates; or better still, with a stout central zinc rod, surrounded by a perforated carbon cylinder. As the operator may be desirous of constructing his own battery, a brief description is given here which will enable him to make up such a cell, of which from six to eight will be required to work the above-described coils to perfection. Having procured the requisite number of perforated carbon cylinders (which are stock articles with some electricians), size about 7 in. long by 3 in. in diameter, he will procure an equivalent number of good glazed stoneware jars (Westall's salt jars or 2lb. plum jam jars will do if nothing else is available) of about 4 in. inside diameter, and from 6 in. to 6½ in. in height. He will also require an equal number of stout round zinc

rods, about 7 in. long and from $\frac{3}{4}$ in. to 1 in. in diameter, fitted with a stout wire at top for future connection to terminals. These zincs must be well amalgamated. The next operation is to solder a thin sheet copper strap about $\frac{1}{2}$ in. wide round the top edge of each carbon cylinder, and then, with a $\frac{1}{8}$ in. drill, to drill two holes at opposite points in the diameter, very cautiously so as not to break the carbons, right through the copper collar and carbon cylinder. Six wooden caps must now be turned up. These should be about 1 in. thick, and of the same diameter as the outside of the carbon cylinders. They should be turned down for about $\frac{1}{2}$ in. of their thickness, so as to enter freely into their carbon cylinders, to which they will form a kind of lid. After having been duly turned up and sandpapered, and a central hole put through each to admit the stout wire attached to the zincs, these wooden covers should be boiled in melted paraffin wax, until no bubbles rise. They may then be taken out to drain and cool. When cold the wire from the zincs, having been cleansed, straightened and tapped with a screw thread to fit a suitable female screw nut, is passed through the central hole of the wooden cover and cut off at about 1 in. from the top thereof, and the nut then run down to fasten the zinc in its place. The carbon cylinder is now fitted with this lid, with the copper strap uppermost, *i.e.* at the same end as the lid, and fastened thereto by means of two rather long $\frac{1}{8}$ in. brass wood screws with round heads. Under the head of one of these screws in each cylinder must be fastened a thin copper strip about $\frac{1}{2}$ in. wide and 5 in. long to

serve as connection to zincs, or to outer circuit. The battery is now virtually complete; but if desired, for greater convenience, the cells may be fitted in a long narrow wooden tray, wide enough inside to take one of the jars and long enough to take the six or eight which it may be intended to use. From the two extreme sides of this tray should arise two standards, about twice the height of the jars, across which should play a long straight iron rod fitted at one end with ratchet and pawl, and at

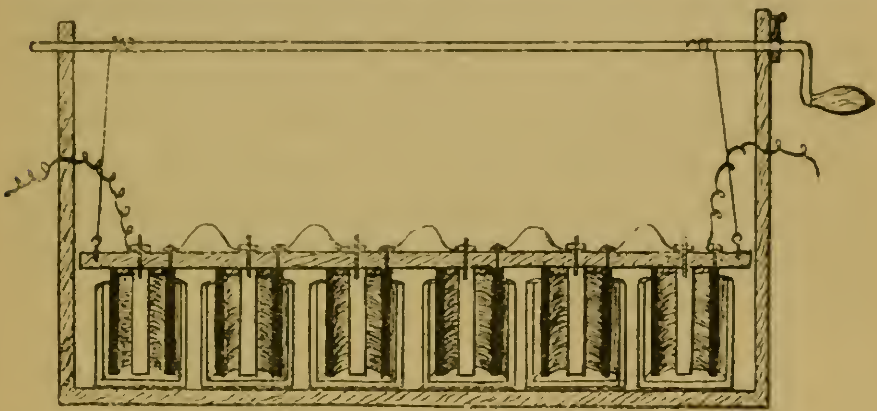

FIG. 18.—BATTERY IN TRAY.

the other with a cranked handle. A strip of hard wood nearly as long as the space between the two standards, $\frac{1}{2}$ in. thick and 2 in. wide, is now procured, and after being paraffined has a sufficient number of $\frac{1}{8}$ in. holes drilled through, at equal distances along the central line, to allow the threaded wires arising from the zincs to slip through. The nuts (having been previously removed from the covers) are in this case run down on to the transverse strip of wood itself. This enables the whole

set of carbons and zincs to be removed from or plunged into the acid in the jars at once. A couple of metal eyes screwed into the centre of the wooden strip at each extremity, to which are fastened a couple of pieces of catgut attached to the metal rod lying across the standards, complete the necessary arrangement, which is shown at fig. 18, in which the cells, carbon, &c., are shown in section to avoid confusion. For working the afore-described coils, these cells should be joined up in *series*—that is to say, the zinc of the one cell should be connected to the carbon of the next by means of the copper strip, and so on, the first carbon and the last zinc forming the terminals which are to be connected to the coil. The best solution for exciting this form of battery is certainly one containing chromic acid, and the following recipe will be found satisfactory both as regards efficiency and lasting effects:—

Chromic acid	3 parts by weight
Water	20 parts by measure
Sulphuric acid (sp. gr. 1·845) . .	3 parts by measure
Potassium chlorate . . .	½ part by weight

Owing to the action of the sulphuric acid on the water, this solution becomes hot on first mixing. It must not be used until cold, and care must be taken to pour the sulphuric acid in a fine stream *into the water*, and not *vice versâ*, otherwise an explosion may take place, due to the sudden evolution of steam.

§ 30. Accumulators are another convenient source of current for working coils; and as usually the duration of each experiment is not great, it is not necessary to

have very large cells. Owing to the difficulty of 'forming' the plates, it is not advisable for the operator to make them himself,[1] and it is strongly recommended that he should procure six or eight cells of the 7-plate Q type made by the E. P. S. Co., which have a capacity of about 21 ampère hours. To use these cells, the cells should be filled to about ½ in. over the level of the plates, with dilute brimstone sulphuric acid, sp. gr. 1·190. The cells should then be put in series, and charged from a suitable dynamo until the sp. gr. rises to 1·22. This can be ascertained by means of a hydrometer. The charging current for the Q type cells need not exceed 4 ampères, and if eight cells are coupled up in series the E.M.F. of the dynamo need not exceed 20 volts. There are a few precautions connected with the management of accumulators, the observance of which will greatly conduce to their maintenance in working order. First, an accumulator should never be short circuited, as the sudden discharge which would take place would buckle the plates and dislodge the paste. Secondly, the discharge from the cells should be limited to about 2½ ampères per plate. Thirdly, no cells should be allowed to remain discharged—that is to say, indicate a less voltage than 1·9, or a lower sp. gr. of acid than 1·15, for more than two days. Fourthly, if by any chance the cells have been allowed to run down, and white patches, due to 'sulphating,' show themselves, the best remedy is con-

[1] In case the student should be desirous of trying his hand at making his accumulators, he will find full instructions in the author's *Electrical Instrument-making for Amateurs*.

tinuous re-charging, and the addition of about $\frac{1}{5}$ of sodium sulphate to every part of strong sulphuric acid originally employed in making up the solution. Fifthly, to avoid electrical leakage, the greatest care must be used to keep the outside of the individual cells free from the condensation of moisture, and this object may be attained by wiping over the outside of the cells with a rag smeared with vaseline, or by standing the cells on glass strips. Sixthly, in mixing the acid solution for an accumulator, care is required to avoid accident. The strong acid must be very gradually poured into the water to avoid splashes, and a too sudden rise of temperature. The water *must never be poured into the acid.*

§ 31. The employment of a dynamo for working a coil, unless the dynamo be specially constructed for the work, is hardly to be recommended. A continuous current dynamo, with armature of the ring or drum type, with a many-part commutator, and having an E.M.F. of about 16 volts, and capable of delivering a current of from 14 to 20 ampères, would work either of the above-mentioned coils well; and it would be advisable to have in connection with it a switch to cut off the current, and a graduated resistance in order to be able to regulate the amount of current sent through the coil, and thus obtain the best results without endangering the insulation of the coil. Such a dynamo would require about $\frac{1}{3}$ h. p. to drive, and would be found perfectly satisfactory in practice. It would not be advisable to employ the ordinary dynamos used for lighting, since usually their voltage is much too high, so that without a proper sliding

resistance, the value of which would have to be ascertained by testing the voltage of the dynamo and the resistance of the primary of coil, there would be great risk of breaking down the insulation of the latter.

§ 32. It is possible and sometimes convenient to work a coil with a current supplied by an alternating dynamo.

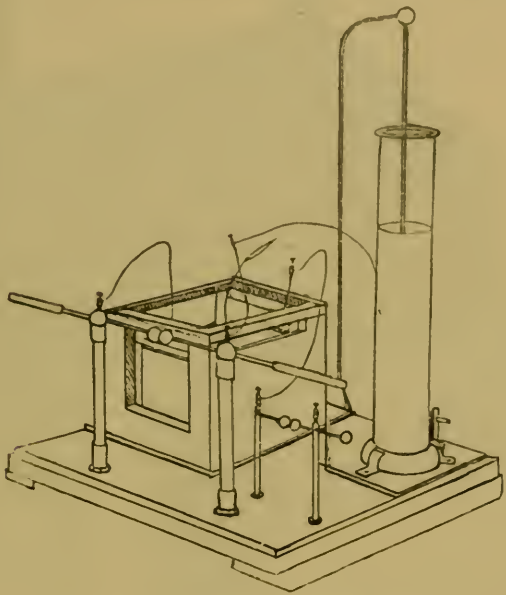

FIG. 19.—TESLA TRANSFORMER.

In this case the clapper or vibrating hammer must be retained against the contact screw by placing a slice of cork, of sufficient thickness, between the hammer head and the coil core. It is even more essential in using an alternating current that a sufficient resistance should be used in circuit with the dynamo and coil than is the case when a continuous current dynamo is employed.

Personally, the author has never found the alternating dynamo very satisfactory when used in conjunction with the coil. This is probably due to the fact that the

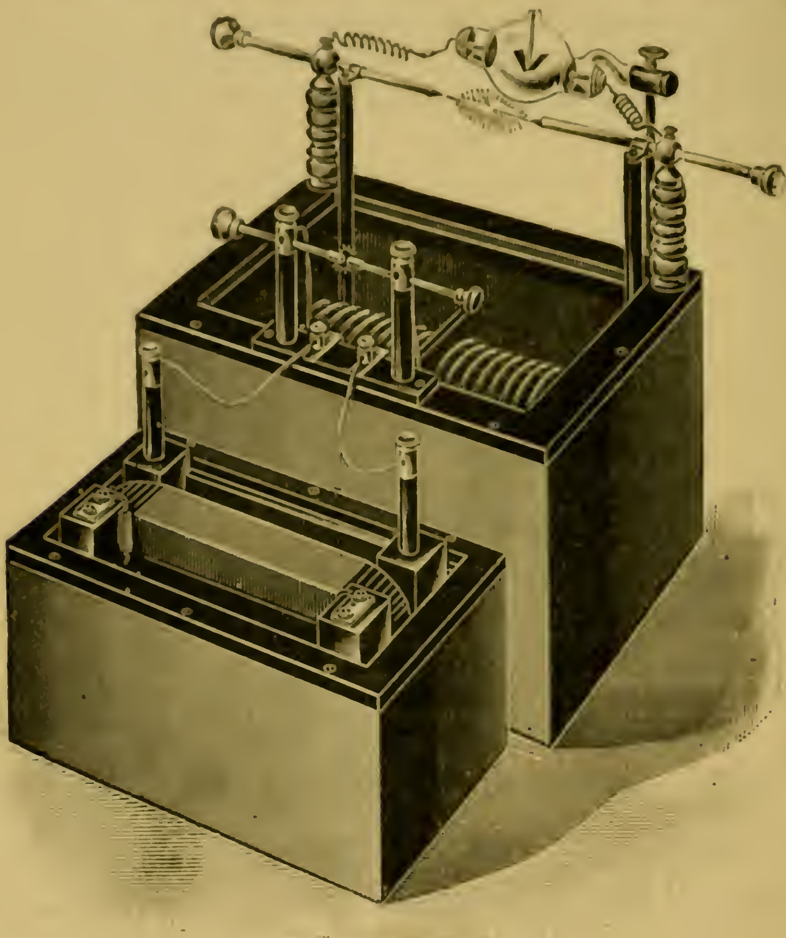

FIG. 20.--TESLA TRANSFORMER.

alternations, instead of being clean and sharp, as represented graphically by , partake more of an undulatory character, as shown .

§ 33. There is, however, a modification, or, to speak more exactly, an addition to the ordinary coil, known as the 'Tesla' transformer, which may be used in conjunction with the alternating current dynamo, that gives fairly good results. We present illustrations of two forms of 'Tesla' apparatus at figs. 19, 20, and 21. These

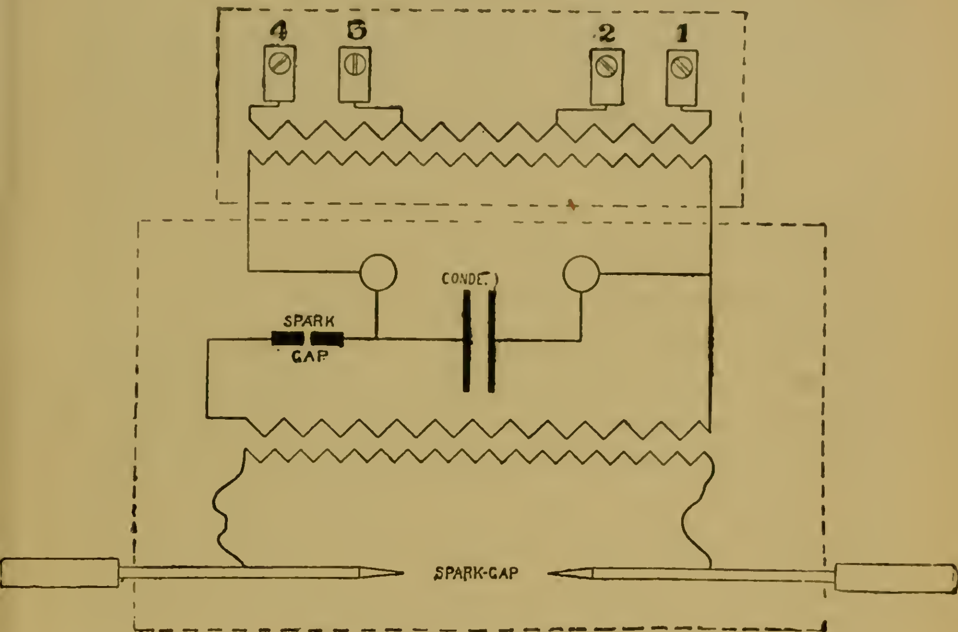

FIG. 21.—TESLA TRANSFORMER.

latter are constructed specially to run off the ordinary 'alternating' street mains. The following instructions may be useful to those intending to try this latter form of 'Tesla' as a source of electricity for working the tube. First, the large box containing the 'Tesla' coil must be filled with mineral oil to within ½ in. of the top of the stoneware lining. The whole should then be allowed to

stand for three or four hours, to enable the oil to penetrate and displace any moisture which may have settled on the winding; secondly, the small box containing the step-up transformer must also be filled up with the same quality oil, until it begins to flow over the wooden cover under the primary winding; thirdly, to connect up, the street mains are to be coupled to the terminals on the smaller, or step-up transformer, as follows: for weakest power, terminals 1 and 4; for intermediate, terminals 2 and 4; for strongest, terminals 3 and 4. The terminals 1, 2, and 3 should never be used with each other; fourthly, the wires from the step-up transformer are to be connected to the terminals fixed on the flat ebonite, immediately under the spark-gap of the 'Tesla.' The end of the spark-gap discharger should stand about $\frac{3}{32}$ in. apart at the commencement, and the distance be gradually increased till the full effects are obtained. It must be particularly noted that the step-up transformer can only be used (within very small limits) for that particular voltage and periodicity for which it has been constructed. If used on a lower periodicity the primary winding outside the oil will become hot, but no danger need be apprehended to the fine winding in the oil, until the oil itself becomes quite hot. A great deal of difference of opinion appears to prevail as to the value of the Tesla apparatus for X ray work. Some operators appear to have been very successful with it, while others record nothing but failures. It would appear that the difference of result obtained depends largely on the frequency, or otherwise, of the alternations; for there is no doubt that

a great deal of the penetrative power of the rays set up depends upon the frequency and cleanness of the oscillations. In fact the author has seen cases, in which, by means of special devices, the oscillation rate, having been considerably heightened, substances which are comparatively opaque to the ordinary X rays (such as bone) have become fairly transparent. This effect, however, is accompanied by the converse, viz. certain substances which are transparent to the ordinary X rays become partially or totally opaque to the modified rays.

CHAPTER V

CROOKES' TUBES: STANDS

§ 34. THE forms given to and the modes of constructing the high vacuum tubes, which are employed for the production of the X rays, are very numerous, and vary with the application to which they are to be put. Essentially the tube consists in a glass bulb containing one platinum anode, and one or more aluminium, or platinum faced aluminium cathodes, at opposite extremities of the tube, these anodes and cathodes being respectively connected to loops or terminals on the outside of the tube, by means of platinum wires encased in glass, which are fused into the main tube, or bulb, during the process of blowing. Some makers, with a view to being able to regulate to some extent the degree of vacuum in the tube, introduce a piece of palladium in an extension, also of glass, attached to the main bulb. In this case the bulb is filled with hydrogen gas previous to exhaustion, so that the vacuum is really a *hydrogen vacuum*; in other words, what little gas is left in the tube, after exhaustion has been carried as far as desirable, is hydrogen. Palladium has the peculiar property of

absorbing or 'occluding' 960 times its own bulk of hydrogen gas at ordinary temperatures, which is given off on the application of heat; so that by warming that portion of the bulb, or its prolongation in which the palladium lies, the vacuum can be lowered to some extent. The tube is exhausted of its contained air or hydrogen by means of a Sprengel, Fluess, or similar air pump, until the vacuum is equivalent to 2 millimètres in the barometer. We present the reader with an illustration at fig. 22 showing the more generally useful forms of tubes. No. 1 is the old form of Crookes' tube, in which the rays impinge directly upon the glass or screen, without the intervention of a reflector. Nos. 2, 3, 4, 6, 7, 10, 11, 12, 13, 14, 17, 18, 20, 21, 24, 26, 28, 32, are of the same type, the modifications being simply structural. Nos. 5, 8, 9, 15, 16, 22, 23, 25, 27, 29, 30, and 31 are tubes of the modern 'focus' type, in which the platinum anode takes the shape of a reflector, and thus throws the rays, starting from the cathode, in any desired direction. No. 2 represents a form of tube which is used when it is desired to cause a movement of the cathode stream by means of a magnet. The concave cathode in No. 3 is brought very near the glass, so that its focus is really on the outside of the tube. No. 4 shows a tube with a cathode which can be revolved in a plane at right angles to its own face. No. 5 is furnished with two cathodes, and the rays from them are reflected from a platinum anode. In No. 6 we have a tube in which the anode is formed of an aluminium disc, which, it is stated, is transparent to, and is tra-

versed by the cathode rays. The advantages of this arrangement, however, are not very evident. In No. 7 as in No. 5 two cathode streams are utilised. No. 9 and a modification of it, which will be described and figured later on, has two anodes, one of them a platinum cone, which reflects the cathode rays. The tube shown in No. 10 is said to be especially useful with currents of high frequency. It is uni-polar and has an external anode. As far as the author's personal experience goes, this tube is of no practical use for radiography or for screen work, as the glass soon becomes perforated at the part where the external anode is placed. No. 11 has pointed poles, either of which may be used as the cathode. This is not a form to be recommended. In No. 12 we have a platinum cathode covered on its convex side by a glass insulator, the idea being to reduce the loss of radiation, but it seems very doubtful whether the glass capping has any such effect. No. 13 is a good form of tube for fluorescent screen work, but owing to the fact of its having no reflecting anode it requires a very high E.M.F. to give satisfactory results. No. 14, like No. 10, is uni-polar, having the cathode in the tube and the anode outside. The observations made with reference to No. 10 apply also to this tube. No. 15 has a cathode on each side of the anode, and the design of this form is to enable two photographs to be taken at once by the reflection of the rays from the cathode on either side. This, to say the least of it, is a very doubtful advantage, since it is impossible to place the same body on both sides of the

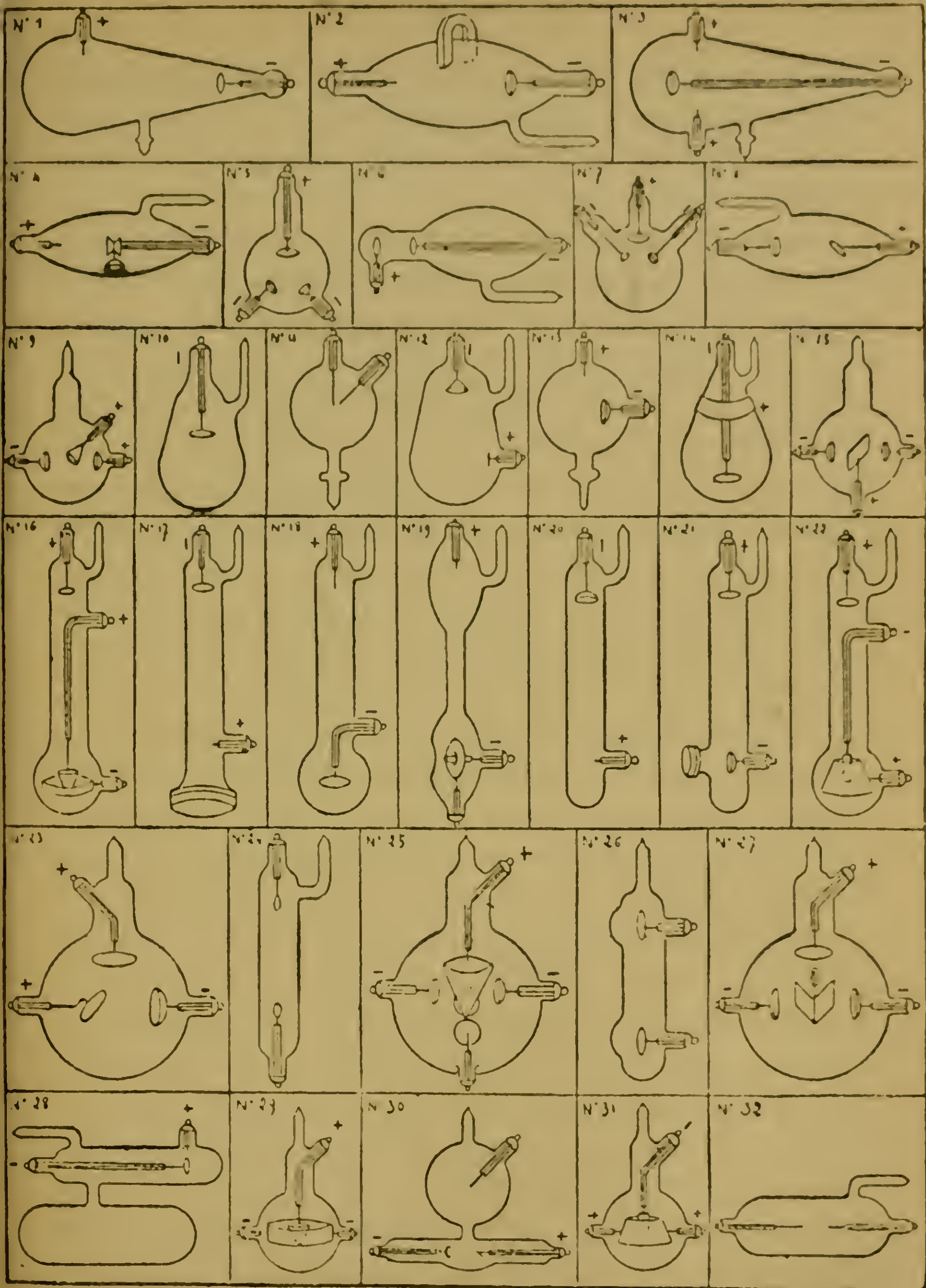

Fig. 22.—Different Forms of Crookes' Tubes. F 2

tube at the same time, and very unlikely that two bodies will be required to be radiographed at the same time from the same tube, under precisely the same conditions of exposure, &c.

In No. 16 we have a tube which is designed to throw the cathode rays in an annular reflection, there being a circular disc for the cathode, and a hollow cone of platinum as the anode in its centre. It is sometimes desirable to investigate the action of the cathode rays upon different substances inserted close to the point of emission. No. 17 represents a tube constructed for this purpose. The substances can be inserted in the trumpet shape end of the tube. Another form for this purpose is figured at No. 18. Here the anode is placed at the top, while the cathode is placed reversed at the bottom, or bulb end of the tube.

In No. 19 we have the result of an attempt made to combine both the direct and reflected anode rays. The cathode passes through a concave anode of platinum, and all the rays emitted by it are utilised, either directly or after reflection. In No. 20 we have an illustration of a tube which was used at the commencement of Röntgen ray work. A good point about it is that the poles are a good distance apart, so that there is little danger of sparking taking place outside the tube; but owing to the fact of there being no reflector this tube is slow in action. At No. 21 we have a tube in which there is an interchangeable window in front of the cathode. This is intended for testing the permeability of different substances. A Bianodic tube is represented at No. 22, and

is designed on the principle of the reflection of the cathode rays, there being a cathode placed centrally inside the reflecting anode. Another Bianodic form is shown at No. 23, and it is this, with a slight modification, which has given the best results in the author's hands. No. 24 illustrates a tube in which both the anode and cathode are made of aluminium discs, and, as these are precisely similar, either pole can be used as anode or cathode indifferently. In No. 25 we have a form of tube designed to be used with four coils, there being a platinum cone as the central anode, which serves to reflect the light from four cathodes placed around the circumference of the tube. A tube useful for showing the place of origin of the active rays is shown at No. 26. Our next illustration, No. 27, shows a tube having two anodes and two cathodes. It is supposed that the two cathode streams reflected from the anodes meeting with one another gain additional power. Whether these two latter forms are really advantageous in practice is doubtful, except only where an intense effect is required to be localised over a small area, since more coils, or more E.M.F. is needed, than is the case with the single cathode forms. No. 28 shows a form of tube in which a vacuum regulating bulb is added to the main tube; this bulb may contain some substance which has the power of occluding the gas in which the vacuum is produced. In general behaviour it resembles No. 10, but it has the defect of becoming rapidly heated. The form shown at No. 29 is designed with the intention of concentrating the cathodic rays to a point. This is

effected by giving an annular form to the cathode, which is made in the shape of a flat ring of sheet aluminium surrounding the conical central platinum anode. No. 30 is designed to show the effect of the reflection of the anode rays in as small a space as possible. This tube is also provided with a palladium electrode. A form

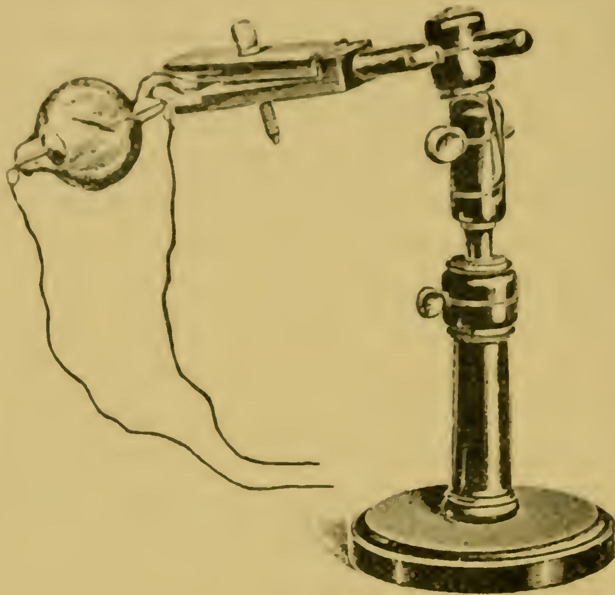

FIG. 23.—JOINTED STAND.

which has been found to give exceptionally good results with fluorescent screens, owing to the large area evenly covered by the reflected rays, from the large annular surface, is figured at No. 31. No. 32 represents the tube of the form originally employed by Röntgen in his classical researches. Nos. 1, 2, and 20 are known as 'Crookes'' tubes, Nos. 3, 5, 7, 9, 11, 13, 16, 17, 18, 21,

22, 23, 29, and 31 are due to M. Séguy; No. 4 is the 'Wood' tube. No. 6 was devised by MM. Chabaud and Kurmuzescu. No. 8 is of the well-known 'Jackson,' or 'Focus' type. Nos. 10 and 14 are of the 'D'Arsonval' type. No. 12 is the Puluj tube; 15, 26, and 27 are

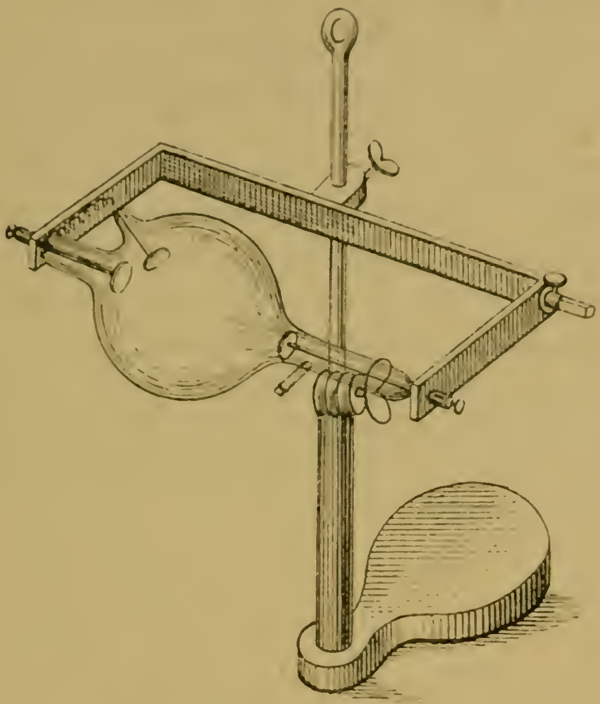

Fig. 24.—Stand for Bianodic Tube.

Le Roux tubes. No. 19 is due to M. Rufz, Nos. 24 and 32 to M. Röntgen. No. 25 is the Brunet-Séguy tube; while Nos. 28 and 30 are the results of M. Colardeau's experiments.

§ 35. As it is important that the discharge should take place inside the tube, and not on the outside, some

attention must be given to the form of *stand* which is employed to support the tube. A very common form is the ball and socket double-jointed stand, which we illustrate at fig. 23. This is best made of wood, with wooden screws. The portion which holds the stem of the tube should be lined with leather, with the double object of giving a better hold on the glass, and of preventing accidental injury. But as some forms of tubes have no stems, which can be gripped by the holder, a stand of the form represented at fig. 24 will be found more convenient. This is the form adopted by the author, and which lends itself to tubes of any shape. It has also the great advantage that even if the tubes are not capped there is no danger of breaking off the platinum loops by hooking and un-hooking the wires. This stand should be made of ebonite throughout, with the exception of the base, which should be of wood, heavily weighted with lead underneath, to ensure stability.

CHAPTER VI

THE WIMSHURST MACHINE

§ 36. There is no doubt that a good induction coil worked in conjunction with a suitable battery, either primary or 'storage,' affords a very convenient and satisfactory means of actuating the tubes which formed the subject of our last chapter. But coils are subject to many ailments, and are very costly, and very apt to 'break down' unless great care is taken in using them. Added to this is the inconvenience, mess, and uncertainty of the batteries which must be employed to energise them. With the exception of the accumulator (and perhaps a good Edison-Lalande coil), there is no battery which can be depended on to give a current of 12 ampères for even an hour without very serious falling off.

The author was one of the first to experiment with the induction machine known as the 'Wimshurst,' as a means of obtaining X rays, and his own experiments, conjointly with those of many others (of which detailed accounts may be found in the pages of 'Nature' and of the 'English Mechanic' for the years 1896–7), have conclusively proved that a good Wimshurst machine, constructed specially for the purpose, and furnished

with special means of connecting up, and thus ensuring clean and rapid discharges, without 'brushing,' is quite equal, if not superior, to a coil in efficiency. The following extract from the 'English Mechanic' of August 6, 1897, relating to experiments made at the Earl's Court Exhibition, on Friday, July 30, in the presence of several experts, will go far to prove that in the Wimshurst we have the best source of electricity for radiographic purposes:—

On Friday evening last several gentlemen interested in the subject attended to make tests and to witness the results which may be obtained from the influence machine which stands at the Earl's Court Exhibition. The tubes were of known value, and had been in daily use for surgical work: one tube was suited to a spark of 3 in. in length, the second required 6 in. spark length, the third was of the highest degree of exhaustion, and required a spark length of, or exceeding, 10 in. Owing to the extemporary nature of all the surroundings, the conditions for making the tests were by no means favourable; nevertheless, the tubes and screens were lighted more perfectly than by the coil which had hitherto worked them; the light partly penetrating the bones of the arm, showing the bone structure of the elbow joint, and passing through the chest. At the conclusion of these tests it was freely admitted that the screen had not before been so brightly and perfectly lighted. The machine was found capable of lighting four or more tubes simultaneously, with the expenditure of about one man power. The feature of *constant* illumination of the screen will, no doubt, apart from many other advantages, cause the Wimshurst to become the best and favourite means for lighting the tubes.

§ 37. In view of the facility with which the Wimshurst can be constructed by any amateur possessing the two qualifications of being able to use his hands and of neatness, it is proposed in the following pages to give

FIG. 25.—FRAMEWORK OF WIMSHURST.

FIG. 26 – COMPLETE WIMSHURST.

a short account of the manner in which a really serviceable machine can be constructed, which shall be capable of causing to fluoresce any well-constructed Crookes' tube of the 'Focus' type, which would require a spark between three or four inches in length to work it.

The stand first demands our attention. For this purpose we require four pieces of mahogany, 1 in. thick and 3 in. wide, two being 2 ft. long and two 12 in. These latter are fastened under the 2 ft. pieces crosswise at their extremities, and should project about 1 in., the result being a rectangular frame, 12 in. wide by 2 ft. 2 in. long. In the centre of each of the longer pieces is erected a standard also made of mahogany, 17 in. long, 4 in. wide at the base, where it is morticed to the frame, and sloping away to $2\frac{1}{2}$ in. at the top, at which it is rounded, and where the spindle which bears the plates will have to run.

The annexed figures (25 and 26) of a stand and of a complete machine will show the disposition of the parts. At 4 in. from the base a $\frac{1}{2}$ in. hole is drilled through each standard, and bushed with stout brass tubing to take a $\frac{1}{2}$ in. steel spindle. At about $1\frac{1}{2}$ in. from the top of the standards, a similar hole is also drilled in the wood, but this need not be bushed, as the spindle which carries the plate does not itself rotate. The driving wheels are now made from $\frac{3}{4}$ in. mahogany, 6 in. in diameter, and these should be connected together the same as the heads of a cotton reel, by means of a wooden core about $1\frac{1}{4}$ in. in diameter, through which a steel spindle passes. This latter spindle must be at least

12 in. in length, and fit fairly accurately the bushing which has been placed in the standards. A V groove must be turned in the 6 in. driving wheels, to carry the gut or leather bands, which serve to transmit the power from the driving wheels to the smaller pulleys that rotate the plates. One extremity of the steel spindle which projects from the standards is cut square, so as to allow a handle or crank to be fastened to it; or, if preferred, a screw thread may be cut upon it, and a female screw made in the tube of the handle itself. A piece of mild steel rod, about ½ in. in diameter and about 1 ft. in length, is now selected to fit accurately in the upper holes of the standards, and a piece of brass tube is cut to such a length as to reach from standard to standard, and only just clear them. It is of the highest importance that this tube should fit accurately the steel spindle just chosen, so that it shall be able to rotate freely upon it without any play. This brass tube should now be cut into two equal pieces; and at one extremity of each tube should be fitted a turned mahogany boss, perfectly flat on one side and slightly curved on the other, about 3 in. in diameter, and about 1 in. thick. At the other extremity of each brass tube must be fitted a mahogany pulley about 2½ in. in diameter, with a V groove cut in it. Before going any further, the brass tube and bosses, with their flat sides facing one another, and their curved sides looking towards the pulleys, should be placed between the standards, in a line with the holes in the upper part of the standards. If the whole has been accurately fitted, the V groove of the

upper driven pulleys will be in a line with the V groove of the large 6 in. pulleys, which serve as drivers, and care should be taken that this is so before proceeding any further. The larger wooden discs, or bosses, on the tubes should allow about $\frac{1}{8}$ in. of the brass tube to project beyond them, on the flat sides.

§ 38. The next step is to fit the machine with the ebonite plates. For this purpose the operator will procure two sheets of good ebonite, not less than $\frac{1}{16}$ in. in thickness, and not more than $\frac{3}{32}$ in.; these should be at least 18 in. square. From these, by means of a trammel or a pair of large compasses, one point of which has been made pretty sharp, he will strike out two 18 in. circles, and by continually turning the trammel, or compasses, he can cause the sharp end thereof, first, to scrape, and, finally, to cut, the disc clean out, so that by this means he will be able to produce two 18 in. discs of ebonite, rather over $\frac{1}{16}$ in. in thickness. It is better to cut out the discs in this manner than to risk breaking the plates by cutting with scissors or penknife; ebonite being very brittle, especially in cold weather, and liable to crack at most inconvenient times and places if scissors be used, while if the ebonite is warmed to facilitate cutting it is apt to warp, after which it is extremely difficult to get the plates flat again. When the 18 in. discs have been cut out, a small circle can in like manner be cut out of the centre of each one. This should be of sufficient size to allow the projecting pieces of brass tube to pass freely. By means of a red-hot knitting needle, or similar piece of stout wire, three equidistant holes are

made in the ebonite, and the plates can then be fastened to the flat faces of the boss by means of three flat-headed screws, which must be screwed up flush with the surfaces of the ebonite. The plates being thus mounted, they can be put between the standards, and the spindle passed through the hole in one standard through the two tubes, so that it projects at the opposite standard. In order to prevent the spindle from moving while the plates are being rotated, it will be well to drill two holes at the upper ends of the standards, countersink them, and fit them with flat-headed screws, which, when driven home, shall bite the spindle; and, to make assurance doubly sure, it will be well (having noticed where the screw touches the spindle) to turn a little V groove at these points, so that when once the screws are tightened up the top spindle cannot move.

§ 39. We must now turn our attention to a little brass and glass work connected with this machine. We shall require two brush carriers, or 'neutralisers,' as they are called. For this purpose we take two pieces of the same brass tube as we used to go over the spindle, about $1\frac{1}{2}$ in. long, and in each piece make a fine saw cut for about $\frac{1}{2}$ in. of its length on both sides of the tube at opposite diameters. These saw cuts give a little elasticity to the tube, so that we can, by pinching the tube, cause it to grip the spindle tightly. At the opposite end of each of these tubes we solder a piece of $\frac{3}{16}$ in. brass wire, about 20 in. in length, and drill a hole about $\frac{1}{2}$ in. in depth, with a fine drill, at each extremity of this wire. In these holes we insert a little

bunch of that fine gilt wire known as 'gold cord,' or 'tinsel cord,' so as to produce a 'brush' projecting about 1 in. beyond the ends of the rods, and in order that the little brushes thus produced shall not fall out we plug the hole with a little wedge of any hard wood. It is needless to remark that these brass rods, to which we have just referred, must be soldered by their *centres* to the brass tubes, which we have just fitted on the spindles. The brass rods must now be bent in the shape of a bow, so that the brushes of gilt cord (which we shall hereafter call 'the brushes') just sweep along the surfaces of the ebonite plates without scratching them.

Our next step is to make a couple of Leyden jars. The most showy ones are certainly those straight white glass jars sold by most philosophical instrument makers; but, unfortunately, they are extremely liable to perforation by the enormous tension of the electricity generated by this machine, and, therefore, the amateur is recommended to procure a couple of the ordinary pint salad-oil bottles (such as are sold by Lazenby), which will be found to stand the disruptive discharges of electricity much better than the far more pretentious-looking jars usually employed. The bottles to which reference is made are of a pale greenish colour, and stand about 10 in. high; they are about $2\frac{1}{4}$ in. in diameter at the bottom. A pair of these should be procured, carefully washed with soda and water to remove all oil, then rinsed with plain water, then again with a little methylated spirits, and, lastly, with benzine, after which they may be allowed to drain and dry in a warm

place. When *perfectly dry*, these should each be fitted into a little mahogany base about 4 in. long and 3 in. wide; of such a size, in fact, as will fit easily into the depressions which are left, one on each side, between the back and front pieces of the frame on which the whole machine is erected. To fit the bottles to these pieces, two circular holes should be cut by means of a large centre-bit, so as just to admit freely the bottom of the bottles; and then the pieces of mahogany should be boiled for a short time in melted paraffin wax, until no more bubbles rise to the surface, when they may be taken out, wiped, and laid aside to cool. This is done for the purpose of rendering the mahogany insulating. The bottom of the hole in the mahogany is now fitted with a circlet of tinfoil, under which a ½ in. strip of very thin brass (not thicker than ordinary writing-paper) is laid, and which projects about 1 in. over the upper edge of the mahogany square, where it must be bent over to lie flat (this applies, of course, to both squares); and through the free end of this little projecting piece of brass passes the tang of a small binding screw, which serves at once to hold the brass in its position on the mahogany, and afterwards to make contact through the outer circuit to the Crookes' tube.

A strip of tinfoil about 2 in. wide, and of sufficient length to go round the outside of each bottle, is now to be pasted round the lower end of each bottle so as to form a ring round it, and it is well, also, to paste a tinfoil circlet on the bottoms themselves, reaching to the last-named rings. The bottles should

be put aside to dry thoroughly, and then filled to the same height as the tinfoil reaches with *small shot*. The necks of the bottles should now be fitted with rather long, soft corks; and these carefully bored out with a hot iron wire to take a straight brass rod, reaching, when the bottles are in their places on the stand, from the bottom of the bottles to the exact centre of the edges of the ebonite plates. These rods should be at least $\frac{1}{4}$ in. in diameter, and they are none the worse for being $\frac{5}{16}$ in. They should be fitted at their upper extremities by means of male and female screws to brass balls (one on each bottle) about $1\frac{1}{2}$ in. in diameter, and to these balls projecting at right angles to the upright rods are to be affixed two U-shaped pieces of $\frac{3}{32}$ in. brass wire, about 5 in. long when bent into the U shape, and terminating in points, which must be slightly bent *inwards* towards the centre. We also require a device for regulating the length of the spark; the easiest manner of effecting this is to take a straight brass rod about a $\frac{1}{4}$ in. in diameter, and of sufficient length to reach, when bent twice at right angles at its extremities, from one ball to the other; and also to rest at the back of that standard, where the driving handle or winch is placed.

To each extremity of the two bent arms of this brass rod is to be screwed a brass ball about 1 in. in diameter; and the centre of the rod, at the part where it will afterwards rest against the front standard, is fitted with a small projecting handle, which may be also of brass, pointing outwards, *i.e.*, in the opposite direction to that

in which the two bent arms which carry the balls are directed. This brass rod, with its two knobs and handle, is to be afterwards fastened to the back standard by means of two brass straps and screws; and, in order that there should be sufficient friction to hold the brass rod in any desired position, and yet sufficient play to enable the operator to adjust the distance between the balls on the jar and the knobs on the spark-gap regulator, a strip of leather may be placed underneath each strap, and the pressure regulated to any desired extent by tightening or loosening the screws which hold the brass straps in position. The proper position for this spark-gap regulator is just under the nozzle of the front standard tube, which carries the neutralising rod. (By front standard we understand the standard where the driving handle is.)

§ 40. Little remains for us now to do. Sixty-four sectors are cut out of tinfoil; each sector should be about 3 in. long, about $\frac{1}{4}$ in. wide at the bottom and $\frac{1}{2}$ in. wide at the top, and both bottom and top ends should be rounded. These sectors should be stuck on the faces of each disc, thirty-two on each, on the sides facing the standards, with their small extremities pointing towards the central boss, and their wider extremities within $\frac{1}{2}$ in. of the periphery of the discs. It is needless to say that these sectors must stand at equal distances apart one from the other, and the quickest way to ensure this is to cut a circlet of paper, the centre of which corresponds to the centre of the ebonite disc, and the circumference to the point at which the inner edges

of the sectors reach, and to divide this paper circlet into thirty-two equal parts by means of a pair of compasses, when, by laying this paper over the centre of the ebonite discs in turn, it is easy to place the tinfoil sectors at regular distances apart around the outer edges of the ebonite discs. Ordinary 'white hard' varnish laid thinly on each sector with a small brush will be found to be the best medium for attaching the tinfoil sectors to the ebonite plates.

Our last operation is to connect the large driving wheels to the small driven wheels attached to the plates themselves, by means either of leather bands, or of catgut; leather bands, the same as are used for sewing machines, furnished with hooks, are, perhaps, the more convenient, as they admit of shortening, and consequently tightening, when they work loose by use. The band from the front wheel—viz., the wheel where the handle is—should pass straight over from the driving wheel to the driven wheel; but the band from the back wheel must be *crossed*, since it is necessary that the two plates should rotate in opposite directions.

§ 41. Our machine is now complete, and we can proceed to try it. For this purpose we begin by placing the neutralising rods with their brushes sweeping the plates, in such a position that when viewed from the front of each plate in turn each rod is standing in the position assumed by the hands of a clock when marking *five minutes to five*. We next rotate the handle of the driving wheel clock-wise, and, if the air is fairly dry and the machine has been properly constructed, the

brushes sweeping lightly across the sectors, as the plates rotate, the machine will begin to generate; and on placing (by means of the little handle) the knobs of the spark-gap regulator at a distance of about an inch from each large ball, sparks should be seen to pass between the two gaps of the regulator and the brass balls of the Leyden jars. These sparks may be much intensified in brilliancy and length by connecting the outsides of the jars (by means of the two terminals) with a piece of copper wire.

Supposing we have got the machine to work properly at the first start, we can proceed to notice on which side of the 'collectors' a 'brush' or a 'glow' discharge is seen (by 'collectors' we understand the two U-shaped pieces which are fastened to the knobs of the jars and which embrace the plates). On examining carefully the points of these collectors in a darkened room while the machine is being worked, we shall find that the collector on the one side has a distinct 'brush' of bluish light, apparently extending from its point to the ebonite plate, while the points of the collector on the opposite diameter of the plates will be seen to glow with a distinct little 'star' without any brush. The operator must carefully notice these appearances; the 'brush' is the sign of a negative discharge, the 'glow' the sign of a positive discharge; but he must bear in mind that the *outside* of the jar connected to the brush or negative discharge is itself *positive*, and this must always be the jar which is to be connected to the anode or square platinum flat of the Crookes' tube by means of which

the radiographs are taken. If any difficulty occurs (through a damp atmosphere or otherwise) in starting the machine, a small initial charge may be given to it, and immediate results obtained by rubbing a rod of sealing wax with a warm, dry flannel, and holding it near the lower left-hand-side half of the ebonite disc, which faces the operator while rotating the driving handle.

§ 42. The next piece of apparatus required is the Crookes' tube, and this the operator must purchase. The best kind of tube to use with the Wimshurst machine

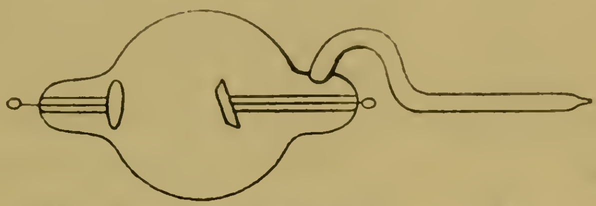

FIG. 27.—JACKSON FORM OF CROOKS' TUBE.

is certainly the 'Focus' type, of which a sketch is annexed (see fig. 27). Such tubes may now be procured at prices ranging from 1*l.* to 1*l.* 10*s.*, and the operator would do well to secure one fit to work with a 3 in. spark; if much less, the exposures required will be long; and if much more, the Wimshurst will not work it satisfactorily in all weathers. In purchasing the tube, care must be taken to select one in which neither the aluminium concave disc nor the platinum flat is at all loose in the tube. Both the aluminium and platinum are fastened into the interior of the tube by means of a platinum wire, encased in an outer glass stem; and as

it is very difficult to ensure perfect adhesion between the platinum wire passing up the glass stem and the glass itself, constituting this stem (owing to the difference in the coefficient of expansion between glass and platinum), it often occurs that either the platinum square or the aluminium disc shakes loose and touches the sides of the tube. The tube in which this occurs should be rejected, as it will be found very difficult to get such a tube to give off the desired X rays satisfactorily.

Having selected the tube, the operator will do well to procure or to make one of those little jointed stands which are used for holding test tubes, or similar articles in which fluids are boiled over a lamp. The jaws of the clamp must be adjusted so as to hold firmly the tail or projecting end of the Crookes' tube, and a couple of binding screws should be inserted at about four inches apart on the woodwork of this stand and connected to the loops of the Crookes' tube by means of a spiral of very fine copper wire. No. 36 gauge will be found a convenient size, as it is sufficiently elastic to prevent any injury being done to the loops of the tube, if it be required to turn the tube on its axis while it is being held between the jaws of the clamp. Fig. 28 gives a good idea of a convenient form of stand and of the proper way of connecting the tube to the terminals thereon.

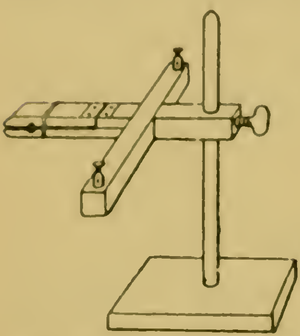

FIG. 28.—TUBE STAND.

§ 43. Our next step is to try whether we are able to get good results with our tube and Wimshurst. To this end we connect up, by means of a convenient length (say about one yard) of No. 18 guttapercha copper-covered wire, the outside of that jar, the collector of which we observe to glow with the 'brush' discharge, to that terminal on the stand which is coupled to the platinum square of the tube, and by means of a similar piece of wire we connect the outside of the other jar to the other terminal of the Crookes' tube stand, which is in connection with the aluminium disc of the said tube.

We now place (by means of the little handle) the balls of the spark-gap regulator at about half an inch from the main balls on the jars, and rotate the machine at such a rate as to get a fairly continuous series of discharges between the four balls. If all is working well, the Crookes' tube will now be seen to glow with a peculiar canary yellow light, and it will be noticed that the light in the tube will seem to divide itself into two distinct portions : the part *in front* of the platinum square and of the aluminium disc will be distinctly canary-coloured, while the portion *behind* the platinum flat will be as distinctly violaceous. If by any chance the tube does not show any yellow illumination at all, but is simply filled with a glow of violaceous light, the spark gap between the four balls must be gradually increased until the above result be attained ; but if, on the contrary, the whole tube seems to glow with a yellow light, and more especially if there is any tendency to sparking between the terminals of the stand itself, it will be advisable to

shorten somewhat the spark gap. It is convenient, though not absolutely necessary for our purpose, to be able to test the presence of X rays without actually taking a photograph, and this can be effected by the use of a 'fluorescent screen' held between the tube and the eye in a darkened room, when, on the hand being placed behind the screen, if the tube is working properly, the hand with its bones will plainly be seen through the screen. Screens are, however, rather expensive luxuries; a description is therefore given of a method of making a simple screen, which, while not quite so good as the shop screens (which are made of barium platinocyanide), will be found sufficiently so to enable the operator to judge of the working condition of his tube. For this purpose he will procure from any of our respectable manufacturing chemists a small quantity of calcium tungstate (about 1 oz. will be quite sufficient for this purpose). He must particularly insist upon having a good crystalline variety, and should examine it for himself, to see that it really glistens with little crystals. He will then take a sheet of stout Bristol board[1] (about 9 in. by 12 in. is a good size), and having brushed over one surface with good gum-water (a Buckle brush is the best for this purpose), so as to get an even coating of gum on the paper, he will spread over the surface of the still moist paper, with a very fine lawn sieve, sufficient calcium tungstate to cover the whole evenly. He will set this aside to dry, and when quite dry shake off any superfluity of the calcium tungstate, which may be kept for making other

* This must be sufficiently thick to be quite opaque to ordinary light.

screens, &c. When he has succeeded in getting his tube to work satisfactorily, he will proceed to try his first radiograph. For this purpose he will procure some of Tylar's light-tight bags (such as most photographers use for carrying their plates about in) of a convenient size. It would be almost advisable for first experiments that he should content himself with quarter-plates. When he has acquired the necessary skill, there will be no objection to proceeding to half- or whole-plates.

§ 44. It would be almost invidious, in view of the large number of really excellent plates which are now in the market, to attempt to recommend those of one maker in preference to those of another; but in order to give the operator some little guide as to the length of exposure and the style of development, we will in the following instructions presume that he is using Cadett's 'Lightning' plates, leaving him afterwards to make use of those plates and of that developer to which he is most accustomed.

Proceeding to the 'dark room,' the operator will place the plate selected in the inner yellow envelope, taking care to have the film against the seamless side of the envelope. Then having closed the flap, he will insert the envelope into the black outer bag with the flap end foremost, using the same precautions to keep the film against the unjoined face of the bag. Having closed the flap of the black bag, he can proceed to the room wherein he has the Wimshurst and Crookes' tube fitted up. Placing the Tylar's bag flat on the operating table, with the film side of the contained plate uppermost,

he will adjust the Crookes' tube on its support, so that the tube stands at about $4\frac{1}{2}$ in. or 5 in. from the level of the table. He must carefully adjust the tube so that the platinum flat points downwards at an angle of 45°, as shown in fig. 29. By this means the cathode rays are reflected downwards on to the plate contained in the bag; and care must be taken to place the bag in such a position that it shall receive equally over its surface the canary-coloured rays reflected downwards from the

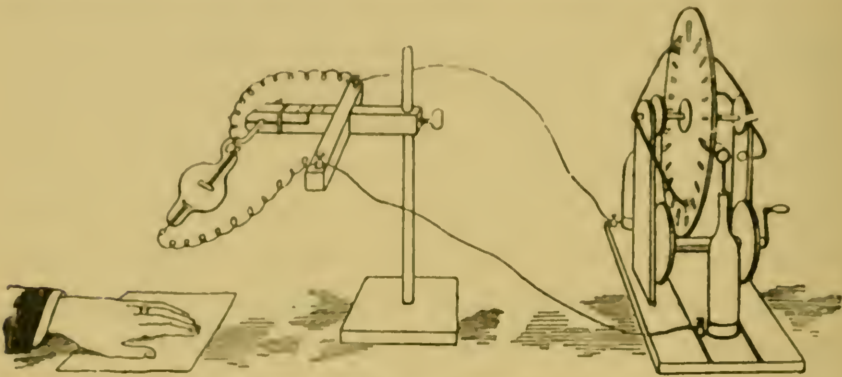

FIG. 29.—ARRANGEMENT OF APPARATUS.

platinum flat. Having thus adjusted the relative position of the sensitive plate and the Crookes' tube, the operator next proceeds to feel with his finger the exact position occupied by the plate in the bag. Having selected an object to be radiographed, say for example a dead mouse, he will arrange this so that it may be contained in the area occupied by the plate, placing the limbs, head, &c., in such a position upon the black bag as to be within the limits of the plate. He will now proceed to turn the handle of the Wimshurst (which has,

of course, been connected up to the Crookes' tube as previously described) at the rate of about three turns per second, or, in fact, at such a rate that the Crookes' tube glows almost continuously with the desired canary-coloured rays.

He must watch carefully during the exposure the state of the tube; if the tube continues to glow with the bright and characteristic canary-yellow light which, if it does not constitute, at least always accompanies the Röntgen rays, he need not vary the speed of rotation, nor alter the position of the balls which govern the sparking gap. If, however, the light should fail, and become violaceous, either the sparking gap must be slightly increased, or else the Crookes' tube must be cautiously warmed, by moving the flame of a spirit lamp about its under surface. But if, on the contrary, the tube glows almost orange in colour, and if sparks should pass between one terminal of the stand and the other, or about the outside of the tube, the spark gap is too great, and the distance between the balls constituting the spark gap must be lessened gradually until the proper kind of illumination has been obtained.

Supposing that all have proceeded satisfactorily, an exposure of about two minutes (in the case of a mouse or a hand) will be sufficient to give good results with the plate before mentioned. Such objects as coins, keys, &c., which are at once thin and very opaque to the X rays, can be successfully radiographed with an exposure of about thirty seconds. On the other hand, a thick, fleshy portion of the body, such as the knee or the elbow, may

take from twenty minutes to half an hour to get a distinct picture of the bones therein contained.

It will not be needful here to dilate on the process of development, since it is precisely the same as for an ordinary negative, and will be fully described at Chapter IX; but for the sake of rendering this chapter complete, in connection with the plates above mentioned, the use of a ferrous-oxalate developer, made as described below, is recommended, as it will be found eminently satisfactory, and to have the great advantage of leaving the shadows quite clear.

Take clean ferrous sulphate, and make with it a saturated solution in distilled water; in like manner make a saturated solution of neutral potassium oxalate. When required for use, measure out three parts of the latter and add thereto one part of the former. It is essential that the order of mixing should not be reversed, otherwise, instead of a clear orange red fluid, a magma resembling pea-soup will be the result.

The developer thus prepared having been poured into the developing tray, the operator proceeds to the 'dark room' and places his first radiograph therein. Here it is recommended that the operator should *not be in a hurry*. The development *may* proceed rapidly, but more probably will take some little time to effect, and it is interesting to note what an amount of detail will come up by prolonging the operation, and how much trouble is saved by not having to intensify the image after development. It is not intended that the student should infer from this that the picture is improved by being under-exposed and over-developed, but simply that he should not lose

heart and cease developing, because detail does not appear at once.

When the image has been developed to satisfaction, the plate should be well washed as usual and fixed in the ordinary sodium hyposulphite solution—strength, about four ounces to the pint. The ordinary processes of washing and drying are conducted as usual. If intensification be required, this may be done at once after the negative has been thoroughly washed by placing it in a solution of bichloride of mercury in water, the strength being about twenty grains to the ounce, and it will be well before mixing the water with the bichloride, which is only sparingly soluble, to dissolve the bichloride itself first in about a drachm of spirits of wine. When the negative is bleached right through and is of the colour of milk on both sides, it should be well washed, and then immersed in a solution of liquor ammoniæ fortis in water—a good strength is about one drachm to a pint of water. Here the negative may remain until it has become brown right through, when a final wash may be given and the negative reared up to dry. From this negative prints may be obtained in the usual manner.

If home made, the whole apparatus, comprising a Crookes' tube, need not cost more than 4*l.* This, of course, does not include the value of the student's labour; but as many have spare time in the evenings, it will be found much more satisfactory, and certainly more instructive, to make such an apparatus, than to spend 10*l.* or 12*l.* over a coil and battery, with the probability of breaking down the coil after the first few experiments.

CHAPTER VII

THE HOLTZ MACHINE

§ 45. Personally, the author has had no experience with the Holtz machine in connection with radiography, but the following extracts from Dr. S. H. Monell's excellent work on Electro-therapeutics [1] go so far to prove the superiority of static machines over coils in the production of X ray effects that no excuse is necessary for their insertion here.

During the first months of the year 1896 the opinion prevailed that: 'Thus far the only apparatus known which will produce X rays readily and profusely is the induction coil. Such a transformer gives exceedingly great electro-motive forces, capable of producing discharge over long air gaps. When the discharge from such a coil is passing through *properly exhausted and constructed tubes*, we have a very vigorous generation of X rays.'

During this same experimental period the static machine was equally known to give exceedingly great electro-motive forces, capable of producing discharge over long air gaps, surpassing in these respects the capabilities of the ordinary coil. It was tried, and for the most part rejected, in early X ray work, for two wholly sufficient reasons which demonstrated that (1) the discharge from

[1] *Manual of Static Electricity in X Ray and Therapeutic Work*, S. H. Monell, M.D. Wm. Beverley Harison, New York, and Sampson Low, Marston & Co., London.

the static machine was not then passed through tubes properly exhausted and constructed for the static current; (2) that scarcely any of the experimenters were skilled in the special manipulation of such an apparatus, and the few who were expert with static electricity could not then procure Crookes' tubes adapted to its great electro-motive force.

Five months later the author (Dr. Monell) was practically demonstrating to physicians in his office and clinic that when the discharge from the Holtz machine was passed through Crookes' tubes, which proved to be 'properly constructed and exhausted' to suit this form of current of extraordinary potential, there resulted a generation of x rays from twenty to thirty per cent. more vigorous and profuse than the product of the best coil known to be then employed, from three to five times more useful to the diagnostician than the x rays of average-priced coils, and incalculably more valuable than the feeble glimmer of the coils and small tubes in most common use. These propositions are deemed capable of demonstration. 1. No surgical consulting-room is fully equipped without an apparatus for x ray examination. 2. The surgical practitioner will consult his own and his patients' best interests by employing an apparatus which is also of great therapeutic value. 3. The medical practitioner can most profitably utilise an electrical apparatus which is not only of prime electro-therapeutic importance, but which constitutes his most practical, economical, and efficient source of x rays. 4. The physician cannot obtain satisfactory x radiance for all-round fluoroscopic investigation and short-exposure photographs with coils of low efficiency, and therefore, comparing effects with cost, such coils are a wasteful and nearly useless purchase. 5. The best coil of either simple or high frequency type possesses drawbacks which will tend to eventually displace it in favour of more satisfactory apparatus. 6. The high potential static current from therapeutic Holtz machines[1] is superior to any coil known to be made at this date (February 24, 1897) in respect to economy, value, efficiency, satisfaction, reliability, and almost all that pertains to the medical and

[1] Or better still the Wimshurst, as being more certain in action and less affected by atmospheric conditions. S. Bottone.

surgical uses of x rays in hospital and office practice. 7. No one can doubt these facts who witnesses repeated practical demonstrations of them, and such demonstrations are easily made by a skilful operator. . . . There is a general confusion of ideas among makers as to what constitutes a 'high-efficiency tube.' Some are satisfied with a display of the bones of the hand. Very few makers or expert operators really know the full capabilities of a superb tube, for few have seen them developed. Common tubes of ordinary vacuum are now plentiful. They will glow with coils giving from 2-in. to 6-in. sparks, and gratify the wayfaring man, who is amazed to see his own bones; or they will produce negatives of even the trunk of the body in the course of time. These ordinary effects are of but insignificant value in diagnosis. Tubes suited to larger coils giving 10-in. to 12-in. sparks may also easily be obtained. Double focus tubes and alternating currents are also available, and are often regarded as exceptionally efficient. When these tubes are purchased by physicians who have static machines and have read that they can be used to produce x ray effects, the result is almost invariably disappointing. To explain why this is so, and to enable medical users of Crookes tubes to employ their own apparatus successfully, are the objects of this paper. When the bulb of a tube is of a proper convexity it will throw rays upon a screen held at many feet—10, or even 20—from the tube itself. Such a rounded convexity is required to make fluoroscopic examinations through thick bodies, for if the bulb is acutely oval the rays will quickly converge, and the maximum of efficiency fades at once within a very few inches of the tube. If the internal electrodes are too far apart or too near together they impair the effect. The space between them best suited to the large Holtz machine is 3 in., with a margin of ½ in. either way, according to the size of the tube.

Very small or very large tubes are unsuited to static machines as a rule, although the construction and vacuum may be so well adapted to this current as to make exceptions of special tubes. Medium sizes have been the best that I have seen. When the external terminals of a tube are connected directly to the prime conductors of a Holtz machine, we have an immediate and infallible test of the vacuum. What the correct vacuum should be cannot be

stated in terms of fractions of an atmosphere, but the demonstration of its degree is as absolute as mathematics. If it is a very low vacuum the electrical discharge will pass in a bluish stream between the electrodes, and no luminosity will glow in the tube. If it is a little higher vacuum the visible blue stream will disappear, and in proportion as the vacuum rises the green glow will increase in brightness. At the same time the spark stream between the prime conductors is also indicating the vacuum to be very low, or some degree between very low and very high.

A current will pass through conductors in the direction of least resistance. If the vacuum is low its resistance may be so small that it may equal only a small fraction of an inch of air gap. A vacuum so high that a 6-in. spark coil will send nothing through it may demonstrate no more than a 2-in. spark stream between static poles. A suitably high vacuum should force back by its resistance at least 1½ in. to 2 in. of spark stream. The green glow in the tube will then be exceedingly bright, and X rays can be developed of very high efficiency. No tube that does not furnish this demonstration is adapted to large static machines, and if physicians will ascertain the facts before buying tubes they can avoid both disappointment and expense.

The outer terminals of a proper static tube must be about 10 in. apart, and attachment to machine should be made with insulated wire of about No. 18 in size, as the fine wires so often employed sway too readily and leak off the current when the attraction of opposite polarities brings them near together.

I have kept a written history of the behaviour of thirty tubes, tested in recent months, in my office. A tube of lower vacuum than it should possess for convective discharge excitation will produce efficient X rays when the oscillating static current is used with small Leyden jars. The maximum of steadiness and radiance can be found by short-circuiting the poles and then gradually drawing them several inches apart until the best effect is developed. The plates of the machine should revolve as rapidly as is consistent with safety. This method is open to objections. It is noisy, and the oscillations try the eyes. It sets up some heat in the tube, but very little as compared with the street current. The convective method is preferable. When the vacuum is just right the terminals

may be attached directly to the prime conductors of the static machine without employing any jars, coil, or other device. Revolve the plates rapidly, and on drawing the poles apart the tube will instantly light up with the brilliant green phosphorescence so familiar now to all. If the electrodes are in proper relation all the current will be focussed upon the anode, and the bulb will appear in twin diagonal hemispheres—one in eclipse and the other luminous as the sheen of a strong light. If, now, the hand is examined through the fluoroscope, the bones that were merely a black shadow with a tube of low efficiency will be nearly as white and transparent as the soft parts. The beautiful mechanism of the wrist joint will appear in clear detail. A group of metallic objects on the back of a pine board will show through books of 2,500 pages, or a heavy brass tray, such as I use for a foot-plate with my static machine. When a tube does this, I know it is a good tube. By further art of management, such as all tubes require, efficiency can be still further developed, and demonstrate the ribs, the spinal vertebræ, the movements of the heart, and all other effects so far attained by any operator with any means. The tube does not overheat, and there is no apparent tax upon it or limit to the time it may be run at full power. It does not break down under strain, and it cannot be overloaded. The convective current makes no noise. The glow of the tube is as steadfast and unwavering as moonlight in an unclouded sky. This economy in the durability of tubes is a factor of great importance beyond the first cost of the tube, for a tube that has proven its high worth and exceptional capacity is priceless. Money alone will not replace it if it is injured or broken. Moreover, none of the alleged injurious effects of x rays, reported hastily and with more or less sensation, are caused by the static current. It seems well-nigh impossible that alopecia and dermatitis should be attributed to x rays by practical medical observers; but as they have been so attributed, and no one has yet (December 15, 1896) pointed out the error of this view, the simple fact may here be stated that these electrical or heat effects which resemble sunburn result from the action of heavy currents operating large coils, and are not due to x rays. Röntgen's classical report contained the statement, 'The rays have no calorific effects,' and I am not aware that any one has yet

shown Röntgen to be mistaken, and the static current is not electrolytic. The advantages of safety, facility, life of tube, comfort in operating, absence of heat effects, and stability of the radiance are among those afforded the physician by the static machine. The questions of cost and availability are also to be considered. When no tube was made that would operate well with a static machine, the coil was obligatory, but the large coil outfit cannot be used by the physician in medical practice, and is a useless luxury when not producing x rays.

The superior value of an office or hospital equipment, costing no more than an approximately effective coil outfit and capable of a wide range of therapeutic uses, is self-evident. Such an equipment is to be found in the improved Holtz machines now made. This type of electrical apparatus can be operated by the surgeon or general practitioner or specialist far more readily than can galvanic or faradic batteries in their therapeutic work. Instruction in its management can as readily be procured as instruction in the use of any medical or surgical apparatus. But its double advantage of value to the physician in two fields instead of the single utility possessed by the Rhumkorff or Tesla coil would not suffice to displace the coil if the latter was much the most effective in x ray work. The time is nearly at hand when leading hospitals and physicians throughout the country will be deemed behind the age if they are not prepared to employ this aid to diagnosis. It is, therefore, important to point out the satisfactory fact that electro-therapeutics and the maximum of x ray efficiency are obtainable with the same apparatus—to wit, the static machine. I am aware that nearly all the weight of authoritative utterance up to this date is against this conclusion.

Nevertheless, I have never failed to demonstrate its accuracy since I have been able to procure tubes made partly after my own suggestions and adapted to the static apparatus. The whole matter lies in adapting the tube to the apparatus, and not the apparatus to the tube. When this is successfully done, the demonstration of superior efficiency is complete.

I recently showed certain effects to an expert maker of Crookes' tubes, and asked him what a coil would cost which would produce equal effects. His reply was emphatic, that 'no such coil could be

bought at any price, not even for a thousand dollars.' On another occasion another leading maker stood in open-eyed astonishment before a tube in my office which was excited by my eight-plate, 30-in. Holtz machine. The plates were run at high speed by an electric motor, and the screen glowed as if striving to burst into incandescent light. He had seen the best effects produced in the laboratories of distinguished electricians, and he was an accurate judge of progressive advances in this field. He not only came to my office predisposed in favour of coils, but had been informed by world-renowned authorities that the 'static machine would break tubes and was inferior to the poorest coil.' Without a word of argument on my part he gazed at the—to him—marvellous radiance so easily and instantly produced in his own tube, which his own coil would not excite at all, and made the following remark in a deliberately impressive manner: 'I now see that the best way to excite a Crookes tube is with the static machine. No coil will equal it.'

§ 46. To these remarks of Dr. Monell the author can add but little. It is, however, to be noted that though the Holtz machine is undoubtedly an excellent machine, and one that lends itself remarkably well to the purposes of a physician who uses it for therapeutic as well as for X ray work, yet it certainly is not superior to the Wimshurst machine for X ray work pure and simple. The chief defect of the Holtz is the ease with which it loses its charge, and the difficulty of starting it again if atmospheric conditions be at all unfavourable. In fact, Dr. Monell himself, in order to ensure certain starting of his Holtz machine in all weathers, has adopted a small Wimshurst, inside the main case, to act as a 'charger.' [1] Dr. Monell's machine is an eight-plate, 30 in. diameter machine. The author, with a Wimshurst

[1] See page 123 of Dr. Monell's *Static Electricity*.

having a single pair of 21 in. ebonite plates, each having thirty-two sectors, has been able to do all the X ray work described by Dr. Monell, and even to brightly fluoresce certain tubes of excessively high vacuum, which were not amenable to the efforts of a coil giving a 12 in. spark. The peculiarity in this case was that the coil gave quite easily a 12 in. spark; it did not cause the tube to fluoresce; while the Wimshurst, which gave barely an 8 in. spark in air, between the spark gaps (see § 39, latter half) caused the same tube to fluoresce brilliantly. Making every allowance for personal equation, and for the manipulatory dexterity which each individual who is accustomed to use any given type of machine acquires, it may be safely affirmed that any good static machine that is capable of giving a virtually continuous discharge *in one direction*, with an E.M.F. of not less than 300,000 volts, is capable of giving satisfactory results in X ray work, and will be found superior to the induction coil in almost every regard.

CHAPTER VIII

FLUORESCENT SCREENS

§ 47. The attention both of Professor Lenard and of Doctor Conrad W. Röntgen was first drawn to the peculiar properties of the X rays by the fact that certain fluorescent bodies were caused to glow by the effect of the said rays acting upon the said bodies, even after the rays had passed through substances which are opaque to ordinary light. A very large number of bodies are known to be fluorescent, or to become phosphorescent under the influence either of light, heat, or electricity; and several of these fluoresce as a result of the action of the Röntgen rays. That indefatigable worker, T. A. Edison, has subjected to careful trial about 1,800 of the more important phosphorescent and fluorescent bodies, of which we append a condensed list.

List of Fluorescent Bodies

Æsculine
Ammonium Platinocyanide
Barium Platinocyanide *
,, Sulphate
,, Sulphide *
Boracic Acid

Calcium Fluoride (Fluor Spar)
,, Platinocyanide *
,, Sulphate (Selenite) *
,, Sulphide *
,, Tungstate *
Chlorophyll
Corundum
Curcumine (from Turmeric)
Daturine (from the Thorn Apple)
Fluoresceine (Resorcin Phthalate)
Gelatino-bromide emulsion
Glass
Mica *
Obsidian
Pentadecyl-paratolyl-ketone
Potassium Acetate
,, Platinocyanide *
Quinine Sulphate
,, various other salts
Strontium Platinocyanide*
,, Sulphate
,, Sulphide
Succinic Acid
Uranium Fluoride *
,, Glass
,, Sulphate *

Those marked * fluoresce and phosphoresce after direct exposure to the light emitted by the electric discharge, even if it be as feeble as that resulting from an ordinary Geissler tube.

§ 48. Of these, however, there appear to be only three groups of salts which possess the property of fluorescing with sufficient brilliancy, under the influence of the X rays, to render them of any practical service in the construction of screens for this work. In order to avoid

any misconception, it must be understood that in the following pages the word 'fluoresce' will be used to express that quality, possessed by certain bodies, of so altering the vibration rate of certain given undulations (which do not normally affect the human eye) as to change them into ordinary light rays, and thus render them perceptible to our visual sense. For instance, if, by any of the means indicated in the last chapters, we set a Crookes tube in action, and then hold a purse, or a wooden box, containing coin or other metallic bodies, between the tube and our eye, we shall not be able to perceive the contained objects, although we may know (by taking a photographic picture) that undulations of some kind are actually traversing the substance of the purse or the box. But if between the object and the eye we place a cardboard screen, the surface of which has been dusted over with a fluorescent substance, we shall immediately be able to see not only *through* the cardboard, but also *through* the purse or box (which are transparent to the undulation), and thus recognise the presence of the coin or other metallic articles, which being opaque to the same undulations prevent their passage, and consequently their conversion into ordinary light.

§ 49. Among the salts which give practically useful results when made up into screens, only three will be mentioned here. The first and most generally useful is *barium platinocyanide.* Owing to the high price of platinum this is an expensive salt, and can be obtained more cheaply from chemists who deal in the salts of the

precious metals than it can be made by the inexperienced amateur. Still, as the fluorescent property is very closely allied to the perfection of the crystalline condition of the salt, the following instructions for the preparation of barium platinocyanide, by a process which has given satisfaction, may be useful.

Finely powdered platinum black is mixed with twice its weight of dried potassium ferrocyanide, and then subjected to a low red heat in a Hessian crucible. The resulting mass, when cold, is lixiviated with pure water. The solution contains potassium platinocyanide;[1] from this, mercurous platinocyanide is prepared by the addition of mercurous nitrate, which throws down a cobalt blue precipitate. This changes, when heated in the fluid, to white, and is then pure mercurous platinocyanide. This salt, acted on by sulphuretted hydrogen (hydrogen sulphide), yields a precipitate of mercurous sulphide, the supernatant fluid being platinocyanic acid. If to this slaked baryta be added cautiously until the acid will no longer dissolve the baryta, the solution filtered and set aside to crystallise, a crop of fine, bold crystals of a beautiful greenish-yellow colour will be obtained. These must be carefully dried (not by artificial heat) on bibulous paper, and preserved for use in a wide-mouthed stoppered bottle. Although *powdering* the crystals, when they are once formed, does not appear to have any seriously detrimental effect on their fluorescent

[1] This salt is itself highly fluorescent, and can be crystallised from the above solution in the form of thin plates, yellowish metallic by transmitted, and blue by reflected light.

property, there is no doubt that the finer and the more perfect the crystals are in the first instance, the more satisfactory will be their working capabilities when made up into a screen.

§ 50. The next fluorescent body to which we will direct the reader's attention is *calcium tungstate*. Calcium tungstate is found in nature as the mineral 'scheelite,' and occasionally in a very pure and crystalline form, in the shape of colourless, transparent octahedra having considerable lustre. If the reader is fortunate enough to secure a good crystalline and clean sample of scheelite, such as may be occasionally met with, he will have the material for a good screen (specially serviceable for use with photographic plates and films), but among several dozens of samples of native scheelite that have been subjected to the author for examination only one was really excellent, and this was so good as to be nearly if not quite equal, even for direct vision work, to barium platinocyanide. According to T. A. Edison, who, as already mentioned, has instituted a series of most painstaking experiments on this subject, a chemically prepared calcium tungstate, made as recommended in the following recipe, gives results which he estimates as being *eight times as good* as those obtainable with barium platinocyanide. (The author must admit that he has not hitherto succeeded in obtaining such good results *visually*; this may depend on some difference in the proportions used.) The process which has given the above-mentioned results is as follows: 290 parts (by weight) of carefully dried sodium tungstate, reduced to

fine powder, are mixed with 111 parts of dry calcium chloride and 58·5 parts of common salt (sodium chloride) also carefully dried. The mixture is placed in a suitable crucible, and heated in a furnace until the whole is reduced to a fluid condition. The crucible is then withdrawn, and allowed to cool gradually. When quite cold the resulting mass is lixiviated with cold water, which dissolves out the sodium chloride (which is the only other result of the operation), and leaves the calcium tungstate in the form of fine glistening crystals. (Success seems to depend on the perfection of the crystalline state.) These crystals, after being separated from the sodium chloride solution by filtration and subsequent washing on the filter with water to remove all traces of chloride, are allowed to dry thoroughly, and then sifted through a sieve, the meshes of which must not be less than thirty to the linear inch (900 to the square inch). These should be preserved for use in a wide-mouthed stoppered bottle. The above mode of preparation appears to have given very good results. Another method of obtaining good bold crystals is to precipitate the calcium tungstate from the sodium tungstate solution by means of any soluble calcium salt, such as the chloride, the nitrate, &c., and having filtered and washed the precipitate, to allow the resulting calcium tungstate to dry thoroughly; and then, having mixed it with an excess of powdered borax, to fuse it, at a strong red heat, in a Hessian crucible. The heat should be maintained for some time and the fire gradually withdrawn, so as to allow the contents of the crucible to cool slowly. The

resulting mass should then be treated with water, which dissolves out the borax, leaving the calcium tungstate in distinct crystals. These should be washed, dried, and stored as before for use.

§ 51. Uranium fluoride appears to form a good basis for fluoroscopic screens. To prepare this salt a solution of 100 grains of ammonium fluoride should be made in as little boiling water as will dissolve it. In like manner a saturated solution of 400 grains of crystallised uranium nitrate in boiling water should also be made up. The two solutions should then be mixed and once again brought to the boiling-point in a glass flask; the resulting solution should then be set aside to crystallise in a clean porcelain dish. The mother liquor, that consists principally of ammonium nitrate solution, should be poured off from the resulting crop of crystals, which must be allowed to dry in a current of air without the application of artificial heat. When dry, they should be carefully preserved in a stoppered bottle.

There is another method of preparing this salt, which, although somewhat more tedious, gives a purer product, altogether free from ammonium nitrate. This consists in making up a saturated solution of uranium nitrate in water (400 grains to $\frac{1}{2}$ oz. of water), and also of ammonium fluoride (about 200 grains in 1 oz. of boiling water). About half of the ammonium fluoride solution should now be added to the uranium solution, and the mixture agitated. A little sulphur-coloured precipitate will form, which will be all, or nearly all, redissolved on agitation, especially if the mixture be heated in a flask.

When this has taken place the remainder of the ammonium fluoride solution is to be added, as long as the addition causes a precipitate. The mixture is then filtered and the sulphur-coloured powder collected. The filtrate may be again tested with ammonium fluoride solution to see whether further addition still throws down any of the uranium fluoride. All the precipitates should be collected on the filter, allowed to drain thoroughly, then redissolved in the smallest possible quantity of boiling water,[1] and finally set aside to crystallise in a cool, dry place free from dust. The resulting crystals should be collected, dried from the mother liquor, and preserved for use as before recommended.

§ 52. There are two or three substances which, although of comparatively little service for fluoroscopic use *by themselves*, do undoubtedly enhance the fluorescing power of others when used in conjunction with them. Two of these deserve special notice here—viz. *mica* and *calcium sulphide.*

Mica or talc is a natural magnesium silicate, and is now largely employed as an insulator for dynamo commutators, &c. The waste pieces are ground up into rather fine powder and sold under various fanciful names, such as 'Arctic snow,' 'Polar flake,' &c. as a glistening decoration to imitate the effect of snow or hoarfrost on Christmas fancy goods. This powder, if put through a sieve having about 800 meshes to the square

[1] One part of the uranium fluoride is soluble in eight parts of boiling water.

inch, will be found very serviceable to mix with other bodies in the formation of fluoroscopic screens.

Calcium sulphide has long been known to possess phosphorescent properties, and is the basis of 'Canton's phosphorus' and of Balmain's 'luminous paint.' The mode of preparation influences very much the fluorescent and phosphorescent properties of the resulting calcium sulphide, probably in consequence of some slight difference in molecular arrangement. The old-fashioned recipe which follows gives very good results: Mix 3 oz. of clean oyster shells, previously carefully powdered and sifted through a lawn sieve, with 1 oz. of flowers of sulphur. When intimately combined, ram the whole very tightly into a crucible. Lute a cover on the crucible with a little moist clay. Place the crucible in a clear red fire and let it get red-hot throughout; leave it in the fire for half an hour. Withdraw, and allow the crucible to become quite cold, remove the luting and cover, and place the contents in a stoppered bottle. For use, the resulting calcium sulphide must be finely powdered in a glass mortar and passed through a fine lawn sieve.

§ 53. Having now a stock of the materials we can pass to the preparation of the screen itself. Screens may be divided into three classes: first, those intended for direct vision only; secondly, those which are specially intended for use in conjunction with photographic plates in the production of radiographs; and, thirdly, those which serve fairly well for both purposes.

To the first class belong screens made with barium

platinocyanide, with calcium tungstate (or calcium tungstate and mica), and with uranium fluoride. Of these, there is no doubt that the barium platinocyanide is the best, although good samples of calcium tungstate run it very close. Uranium fluoride (also known as Dr. Melckebeke's salt) is good, but decidedly inferior to the calcium tungstate.

For the preparation of screens of this class the operator should procure a sheet of good white Bristol

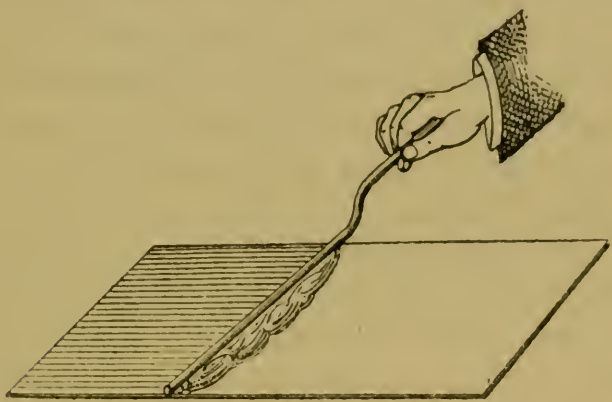

Fig. 30.—Spreading Gum-Water.

board. This should be thick enough to be *absolutely opaque* to ordinary light, and should be tested to this end by holding up in strong sunlight, with the hand or other opaque body behind. A very convenient size for surgical work is 12 in. by 9 in., but a screen 9 in. by 6 in. will be found large enough for general purposes. The sheet having been cut to the desired size is pinned on a perfectly flat drawing-board by its four corners. If calcium tungstate is to be used, a sufficient quantity should

be placed close at hand with a fine wire gauze sieve. A small pool (about as large as a crown piece) of good gum-water should now be poured on the centre of the sheet of cardboard and quickly spread over its surface by means of a glass rod or tube, bent twice at right angles, as shown at fig. 30. Any excess of gum-water should now be swept off the surface of the cardboard by one clean sweep of the tube from corner to corner, avoiding the formation of air bubbles by taking care not to lift the tube during the stroke. The operator then quickly wipes off the excess of mountant (gum-water) which may have been swept on the drawing-board with a clean soft rag, and then immediately sifts some of the calcium tungstate all over the gummed surface, taking care to sift evenly and quickly, so as to get an even covering before the gum has time to dry. When he has covered the screen equally all over to his satisfaction, he tilts the drawing-board on edge over a sheet of paper, and taps the board to remove excess of non-adherent calcium tungstate. If too much gum-water has been allowed to remain on the surface of the cardboard, the resulting coating of calcium tungstate will be too thick, and will be rather opaque to the rays; on the other hand, if too little gum remains on the surface of the cardboard, or, worse, if the gum be allowed to soak in and dry in places, the screen will be patchy and thin in places. The best screen is undoubtedly one on which a thin but even coating of calcium tungstate is spread. For direct vision work it will be found very advantageous to mix intimately half a part by measure of finely

powdered *mica* to one part by measure of calcium tungstate.

§ 54. In the preparation of screens with *barium platinocyanide*, with *uranium fluoride*, &c., as these salts are to some small degree soluble in gum-water (and consequently the perfection of the crystalline form is to some extent impaired if this is used as a mountant), it is better to use either megilp (as sold by artists' colourmen) or celluloid dissolved in amyl acetate. In this case it is well to give the Bristol board a preliminary coating of gelatine. For this purpose about 5 grains of gelatine (Nelson's 'Amber' does very well) are allowed to soak in 1 oz. of cold water, and, when well swollen up, heated until the gelatine dissolves. This mixture is laid evenly on the cardboard with a large soft brush. When this coating is *perfectly dry*, the megilp (or, if preferred, the celluloid solution) is applied to the prepared surface precisely as directed for the gum-water in the foregoing recipe, with these additional precautions: first, in the case of the celluloid solution, to avoid the proximity of flame, lights, or fire, as the vapour is highly inflammable; and, secondly, to apply the fluorescent salts as quickly as possible to the sticky surface, as the solutions both dry off very rapidly. The powder should, as before advised, be sifted over the prepared surface. Some operators recommend, in case of uneven patches arising in consequence of partial drying of the prepared surface, that these spots should be again moistened with the mountant, and fresh salt rubbed in with the finger. Such a mode of procedure is not, however, likely to

produce an even screen; hence great care should be taken at the outset to lay on an even, thin coating of mountant, and then immediately to sift an even and equally diffused layer of the fluorescent salt over the entire surface.

§ 55. The screens heretofore described are intended for direct vision work, and, for convenience of handling, should be mounted in a light wooden frame, as shown

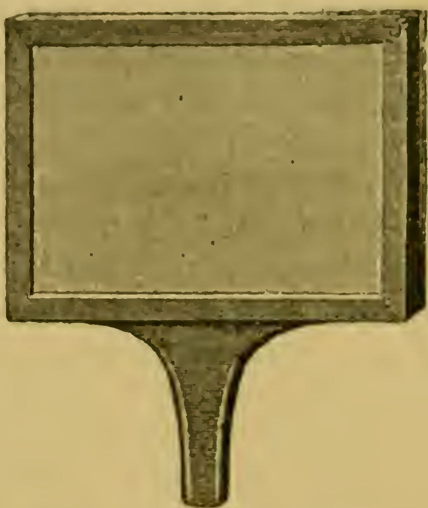

Fig. 31.—Frame for Screen.

in our fig. 31. The frame having been laid flat on a table, the screen, with the prepared side downwards, is laid over it so as just to cover the opening squarely and extend about $\frac{1}{8}$ in. all round beyond. Over this are then laid four thin wooden cleats (fig. 32), which are secured in position by a round-headed screw at each corner, and one at the centre of each cleat. By

this means, not only is the screen held securely in its place, but it is also protected from being soiled or injured, when laid down, by the heads of the screws. It must be remembered that when using the screen the *prepared surface* must be presented to the eye, the object to be examined being placed close against the *plain* surface. To protect the prepared surface of the screen from dust or abrasion, it is well to cover it with a sheet of transparent celluloid. It is sometimes a great assistance, in examining bodies in which there is not much differentiation in texture, to be able to cut off all

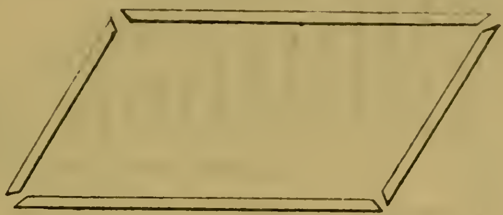

FIG. 32.—CORNERS FOR FRAME.

extraneous rays between the eyes and the screen. For this purpose nothing lends itself so well as a frame with a conical bellows body, having side extensions to cut off light from the sides of the eyes. The larger extremity of this frame has an opening at the top and grooves at the sides and bottom to admit of the mounted screen being slid in; at each side there is a guide-bar and fly-nut to enable the operator to extend and fix the bellows to the degree required to accommodate his sight. The entire arrangement is shown in our fig. 33. Camera bellows of the required sizes and conical form can be

procured ready made from all dealers in photographic camera fittings at very moderate prices, so that, in view of the much greater neatness of the manufactured article, it will hardly be advisable for the amateur to make the bellows himself. When not in use, the fly-nuts at the sides are loosened, the bellows pressed down flat, and the side guide-bars folded over, so that this device can be packed into a small space.

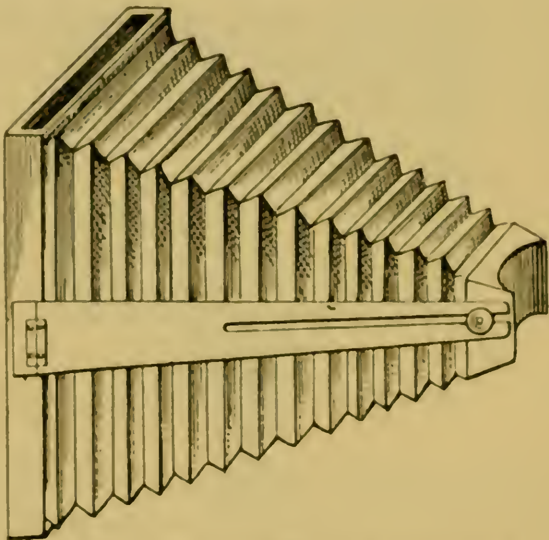

Fig. 33.—Bellows Holder for Screen.

§ 56. It is found that the use of certain screens greatly facilitates the production of the radiographic image on the photographic plate. This is no more than we should expect, for, whatever be the nature of the X rays themselves, it is certain that they do not affect the sensitive surface of the said plate so rapidly as 'light' rays. Hence, if by any means we can alter the vibration rate of the X rays

so as to convert them into light, and more especially if in so doing we can endow them with that particular vibration rate to which photographic plates are sensitive (*i.e.* the highly refrangible rays), we shall be able to shorten very much the exposures required. It will be evident in this case that the screen must lie as close as possible to the sensitive surface, and that nothing except a body which is transparent alike to light rays and to X rays must be interposed between the sensitive surface and the fluorescent surface of the screen. Of course the entire combination must be enclosed in some envelope impervious to ordinary light. If we had at our disposition some fluorescent body which could convert the whole of the X rays generated by our apparatus into light rays, there is no doubt that we should obtain magnificent results, both visually and photographically; unfortunately, none such is yet known, and even our most fluorescent bodies are so far behind the desideratum in this respect that seven or eight screens (covered with fluorescent substance) may be superimposed without entirely blocking out the X rays. Not all the preparations previously mentioned are suitable for radiographic screens. The following condensation of remarks by J. Gaedicke[1] are highly interesting in this connection. Starting with the assumption that the Röntgen rays do not act directly on the bromide of silver, but must be converted by the gelatine or the glass into fluorescent light in order to be photographically active, it naturally follows that an intensification of

[1] *Photographisches Wochenblatt.*

the photographic action must ensue if the rays are converted into fluorescent light *immediately in contact with the film.* This was proved in April 1896 by placing a screen of paper covered with platinocyanide of barium in contact with the film. Although this action was recognised, yet it has found but little use in practice; but now such screens can be obtained conveniently. One disadvantage of these screens is in the granularity of the film, since the barium platinocyanide fluoresces only when it has a particular crystalline form.

In order to test the intensifying action of different salts, strips of paper were coated with them, and the strips pasted side by side on a sheet of cardboard measuring 13 cm. by 18 cm. (about 5 in. by 7 in.). No. 1 strip was left bare, so as to determine the action of the X rays alone; No. 2 was Dr. Melckebeke's uranium ammonio-fluoride; No. 3, the calcium tungstate of the Electricitäts-Gesellschaft; No. 4, Kahlbaum's tungstate; No. 5, Kahlbaum's platinocyanide of barium. In order to determine the action of these salts on ordinary and other plates, a 13 cm. by 18 cm. plate was cut in two, and one half bathed in erythrosine silver, in order to sensitise it for yellowish-green, and dried. The two halves were now placed, together with the above-mentioned compound intensification screen, in contact with the film, and wrapped in a double thickness of black paper, and exposed for thirty seconds to the X rays in such a manner that they had to pass through the screen before reaching the plate. A coil of 10 cm. (4 in.) spark, with rotating mercury contact-breaker, was used,

the tube being 25 cm. (10 in.) from the plate. The deposits on the orthochromatic[1] plate were numbered from 6 to 10, and the experiments were performed by Dr. Baurath. On development, some interesting differences were noted, and the density of the deposits was approximately measured—not absolutely accurately, but still they give satisfactory conclusions as to the action. The following table shows the relative densities of the deposit, that without the screen on the ordinary plate being taken as unity. For No. 10 strip the photometer was too low, and the number is probably much too low in consequence :—

—	—	Ordinary Plate	Erythrosine Plate	—
Without screen . .	No. 1	1·0	1·5	No. 6
Uranium ammonio-fluoride	No. 2	0·5	1·0	No. 7
Calcium tungstate (A.E.G.)	No. 3	2·0	2·5	No. 8
Calcium tungstate (Kahlbaum's)	No. 4	4·3	5·0	No. 9
Barium platinocyanide (Kahlbaum's)	No. 5	0·5	14·0	No. 10

From these figures a series of deductions may be drawn which will be important in practical work.

1. The orthochromatic plate gives a much stronger image than the ordinary without the screen, and it increases the action of all the screens, except those prepared with uranium fluoride. It is thus demonstrated that for X rays only erythro-silver plates should be used.

[1] The portion treated with erythrosine.

2. The uranium ammonio-fluoride reduces the action of the rays to one-half on the ordinary plate, and to about two-thirds on the orthochromatic plate, and ought, therefore, not to be used for this work.

3. The calcium tungstate of the Electricitäts-Gesellschaft doubles the action, and Kahlbaum's preparation quadruples the action on ordinary plates, and gives a yet greater action on orthochromatic plates.

4. The platinocyanide screen gave a very interesting result. With the ordinary plate—which, as is well known, is very sensitive [1] to yellowish-green light—there was no intensifying action, but just the reverse: the screen reduced the action by one-half. From this it follows that this screen had converted the greater part of the X rays into yellowish-green fluorescent light; the orthochromatic plate showed the most intense blackening of all. By these extraordinary differences may possibly be explained the different opinions of others who had obviously used unsuitable plates. The blackening of No. 10 was so strong that it is obvious at the first glance that the use of a platinocyanide screen—but only with an orthochromatic plate—must be the most economical method of using the Röntgen rays.

§ 57. In the preparation of screens specially for radiographic work it is well to remember that as the prepared surface should lie as close as possible to the sensitive film on the plate, and as any mechanical pressure or chemical action (due to disintegration of the

[1] This is evidently a mistake, it should be *insensitive*.

powder on the prepared screen) may affect the sensitive film and give rise to pseudo-photographic effects, special care must be taken to ensure an *even adherent* layer of the fluorescent substance on the screen, and, if possible, not to have to interpose anything between the surface of the screen and that of the sensitive plate. In using barium platinocyanide with celluloid dissolved in amyl acetate as a mountant, or with calcium tungstate and thin glue, this scope is not difficult of attainment. If, however, the screen contains anything which might act chemically on the film by mere contact, some medium which does not stop out the delicate fluorescent light must be employed. For example, in making up a screen consisting of two parts by weight of calcium tungstate to one part by weight of calcium sulphide (see § 52), the sulphur contained in this latter[1] is sure to attack the surface of the sensitive plate, unless separated from actual contact by means of a sheet of some transparent body. For this purpose a thin sheet of transparent celluloid presents many advantages. It will be readily understood that for radiographic use the screens must be unmounted, and the cardboard need not be so thick as when the screens are intended for visual work. We may therefore take it for granted that for photographic work witb ordinary plates, screens covered with either good crystalline calcium tungstate, or better with the mixture directed above—viz. calcium tungstate mixed with calcium

[1] Or, more exactly, the hydrogen sulphide evolved from it by the action of damp air.

sulphide—give the best results; that with orthochromatic plates stained with erythrosine silver, barium platino-cyanide is far and away the best preparation; and that the uranium salts (at all events, with the plates at present at our disposal) actually decrease the photographic results.

CHAPTER IX

GENERAL MANIPULATORY DETAILS

§ 58. This part of our subject divides itself naturally into two distinct branches—first, that which treats of visual examination of bodies more or less transparent to the X rays; secondly, that which treats of the production of photographic pictures by the aid of these said rays, or radiography proper. Beginning with the first division, we will consider the best mode of operating with an induction coil and accumulators, or battery, as a source of current. For this purpose we shall require to test the condition of our cells either by means of a voltmeter or an incandescence lamp of the voltage of the number of cells used. It may be taken for granted that a coil capable of giving from 3 to 6 in. spark will require at least 12, and for the larger size probably 16 volts to work it. Hence a lamp, of about 5 c.p. 12 volts, should glow brightly with the six cells, while a 16-volt lamp would be required to test the eight cells. Presuming that the battery answers these conditions, as to voltage with these lamps, and causes them to light up well, it may be assumed that the amount of current in ampères

supplied by the battery will also be sufficient, since the resistance of the primary of the coil is so low, as compared with that of the lamps, as to allow of the passage of a sufficiency of current. Still, for very accurate work, it is sometimes advisable to employ an ammeter, capable of registering to at least 20 ampères, and a voltmeter of similar reading. In testing with these instruments it must be borne in mind that the voltmeter may be placed alone in direct circuit with the battery or with the accumulators, without any fear of injury either to the cells or to the voltmeter. But this is by no means the case with the ammeter; for if this latter be placed even only momentarily in direct circuit with the battery or accumulator it would run them down very rapidly, and in the later case probably injure them by the sudden discharge, and the consequent buckling of the leaden grids. Besides this, unless the ammeter were wound with very coarse wire there would be the risk of melting the same, or at least of burning up the insulation. For these reasons the ammeter should not be used except when the coil is also in circuit with the battery or accumulator. Owing to its low internal resistance when used in this position it will not appreciably diminish the current flowing, while it will give a continuous and a very convenient indication of the amount in ampères required to produce a given result with the coil.

§ 59. Turning our attention to the coil, it will be found advisable to mark the two battery terminals on its base with + and — respectively, and always to couple up the poles of the battery to the coil in accordance

with these marks. Having done this, it will be well also to mark with a + one cheek of the commutator; then, having placed a suitable Crookes' tube on its stand, as described in § 43, to connect up first in one direction and then in the other to the secondary terminals of the coil. That terminal which, when connected to the *anode*, or platinum flat, of the tube produces the marked division of violaceous light[1] behind the platinum or anode, and canary yellow in front of it, is the positive terminal of the secondary of the said coil, under the conditions of battery and commutator connections, already described, and *this* terminal should be marked +. By this means, having the crosses always in a given position, there will be no loss of time in having to make trials as to which is the positive and which the negative terminal of the secondary.

Care must be taken in making these experiments to avoid taking shocks, which with these large coils are not only dangerous but may even be fatal. To ensure freedom from such accidents it will be well to leave the commutator in the 'off' position, until all handling (necessitated by connecting up battery to coil or coil to tube) has been completed, when it may be turned on in the direction of the crosses. Another important precaution is that of avoiding the use of excessive battery current.

On purchasing a coil information should be obtained of the vendor as to the proper current *in ampères* that may be safely employed with it; and this ampèrage

[1] See § 43, line 16 *et seq.*

should on no account be exceeded, otherwise the insulation may be broken down and the coil irretrievably ruined.

We have already pointed out (§ 24) that the play of the contact-breaker has a very great influence on the length of the spark produced by the coil. When the spring is extremely resilient and not confined in its play, as soon as the current flows round the primary, and long before the iron core has had time to magnetise to the full, the hammer is attracted. Consequently contact is broken and made again *too soon*, so that the result is a poor thin spark. On stiffening the spring, by the aid of the back nut in the ordinary form (see fig. 11), or by means of the tension screw in the Apps's form (see fig. 12), or by the devices introduced into the Vril form, it will be found that the spark length is improved with the length of time the spring remains in contact with the platinum-tipped screw, up to the point of the full magnetisation of the iron core. There is absolutely no advantage in allowing the battery flow to last longer than this: for it must be remembered that *no inductive* effect takes place in the secondary except at the instants when contact is made and broken. There is the serious disadvantage in prolonging unduly the contact that battery power is wasted to no purpose; and in the case of accumulators, which can supply an enormous current for a short time, there is actual risk of spoiling the accumulators, and of fusing together the platinum contacts of the coil, besides heating excessively the primary, if the spring be retained against the contact screw, either by tightening

the tension nut or otherwise stiffening the spring. The careful operator will make preliminary trials, and take note of the kind of adjustment of his contact-breaker required to give the cleanest, longest, and most rapid torrent of sparks. If (which is not generally advisable) he proposes making use of the current from an alternating dynamo, either private or off the mains, besides altering the contact-breaker, as described at § 32, he must be particularly careful to insert sufficient resistance in circuit, in the shape of coils of platinoid or German silver wire, to reduce the current to the 'safe limit' of his coil. Want of attention to this will surely culminate in a breakdown of the insulation of the coil.

§ 60. Owing to the comparatively small ampèrage of the currents given by the coil, the wires which serve to connect up the coil to the tube need not be very stout, but it is essential that they should be well insulated. For this purpose No. 24 B.W.G. copper, covered with gutta-percha till it measures No. 16 B.W.G., will be found very serviceable, and even when thus insulated should not be allowed to rest on anything but good insulators (glass, ebonite, vulcanised fibre, &c.) on its way from the coil to the tube. It may sometimes be found necessary, in consequence of one of these wires becoming detached from the tube terminals, &c., to manipulate the wire whilst the current is on. In this event a pair of long ebonite forceps may be used ; but it is in all cases far better to cut out the battery current, by placing the commutator in the 'off' position, before attempting to handle the secondary terminals or the wires proceeding from them.

Some tube stands have terminals on their bases, to which the wires from the coil are to be connected; and these terminals have wires leading to the loops of the tubes. In this case these stand wires should be very fine and flexible, to admit of the tube being placed in any position without straining *its* loops or breaking the wires; and for this purpose a sufficient length of No. 36 silk-covered copper wire, previously coiled into a rather tight helix round a stout knitting-needle, will be found most convenient. It will be readily understood that both the gutta-percha-covered wires and those covered with silk must be bared at their extremities and carefully cleaned, in order that they may make good electrical contact with the terminals or with the tube loops. The tube having been placed in position on the stand, and the wires from battery to coil and from the coil to the tube having been duly connected, the screen being placed conveniently at hand, the room should be now darkened and the current turned on. If the precautions previously recommended have been carefully carried out the tube will at once fluoresce in the proper manner—viz. with a clear canary-yellow light in front of the platinum or anode, and a darker zone of purplish glow behind the anode. The position of the tube when used with the screen should be such that the flat surface of the platinum anode faces the operator, so that he can conveniently receive the rays reflected from it when looking down upon it, either in a standing or sitting position, as circumstances may require. Should by any chance (in consequence of some mistake in connections)

the tube *not* be illuminated as above described, should it show the yellow light *behind* the anode instead of in *front* of it, the commutator must be immediately turned by a semirevolution into the opposite position. It may even happen, though this is not likely with a new tube, that the light, although showing correctly, is patchy, with streaks of brilliancy, like hair lines, at some points near the stem of the tube. This would indicate a flaw in the glass, dependent either on an incipient and very fine crack, which will surely extend and allow the air to enter, or upon a break-down in the tube itself, caused through having allowed one of the conducting wires, or other conductor, to touch the surface of the tube, while the current was turned on. It is not advisable, except in the case of wishing to alter the condition of the tube, to send the current in the reverse direction, because the surface of the platinum flat, or anode, is volatilised if used as a cathode, and carried in the form of black smoky deposit to the inner surface of the tube. Supposing, however, the tube to be acting properly, the screen is now held at a distance of about 2 or 3 in. from the glowing tube, with the prepared surface facing the observer's eye, while the body to be examined is held close against the back, or plain unprepared surface. The efficiency of the tube may now readily be gauged. A good 'focus' tube of the Newton or 'Penetrator' type, working with a coil capable of giving a spark from 3 to 4 in. in length, should enable the operator to see clearly not only the bones in his fingers, but also those of the wrist and forearm; and a block of wood about 4 in. thick, with nails in its under

surface, should be rendered almost transparent and reveal the position and the shape of the nails very distinctly. We have already illustrated the 'Jackson' form of focus tube at our fig. 27; we here present the reader with the 'Penetrator' form, due to Messrs. Watson & Son, of High Holborn (fig. 34). With a 'bianodic' tube similar to the one shown in fig. 24, and capable of working with from 6 to 9 in. of spark, it is possible to see the vertebræ and the pulsations of the heart through the walls of the chest.

FIG. 34.—WATSON 'PENETRATOR' TUBE

§ 61. The choice and management of the tube demands some little care. The choice depends to some extent upon the particular use it is intended to put the tube to. In any case the tube must have a vacuum proportionate to the E.M.F. of the coil, or static machine (be it Wimshurst, Holtz, or other), which is to be employed to excite it. It must be remembered, however, that the exhaustion of the tube must be carried to a certain point, since below this no X rays are produced; and, as this degree of vacuum presents a very considerable resistance to the passage of the current, it is virtually impossible to produce a serviceable tube that will work satisfactorily with less than an E.M.F. of

100,000 volts, or, say, a 2-in. spark. On the other hand, it is possible to go on increasing the vacuum in the tube to such an extent that, owing to the enormous resistance presented by it, no current can be forced through it by the most powerful coils in our possession. The best way to test a tube is to notice its behaviour when properly connected either to the coil or static machine with which it is intended to work. If the tube give a pinkish light throughout its length when the little battery power is used with the coil, or in the case of the Wimshurst when the spark gap is very small (say, ½ in. on each side), and refuses to give the well-known canary-coloured glow on increasing the current strength, the vacuum of the tube is *too low*. Such a tube should be rejected at once, as it will be unserviceable unless re-exhausted.

If, on the other hand, when a coil is working at its best possible, or when the spark gap of the static machine has been opened out to its fullest extent, the tube absolutely refuses to glow, or glows only with an intermittent flash, while the coil, &c., is seen to discharge itself on the outside of the tube, either in the form of a spark or a brush from the connecting wires, the vacuum of that tube is *too high* for the E.M.F. employed with it. It often happens that a tube which at first appears to have too high a vacuum may be coaxed by judicious treatment into working well, and such a tube generally turns out to be an excellent one. The qualities of a good tube are, as we have already pointed out, first, immediate and continuous greenish canary-yellow glow,

brilliant enough to allow the time by a watch to be read at 5 to 6 feet distance when the current is turned (this glow to be in the space between the anode and cathode); secondly, a distinct violaceous zone behind the platinum anode; thirdly, distinct and clean differentiation of the bones and flesh of the elbow and knee when employed in conjunction with a good barium-platinocyanide screen. A tube having a rather low vacuum may sometimes be made serviceable by connecting it to the coil or Wimshurst in the direction opposite to the correct one—that is to say, by connecting the negative terminal of coil, &c., to the anode (platinum flat) of the tube. Brilliant and erratic coruscation will be seen to take place, very often marked by patches of brilliant green light, apparently adhering to portions of the bulb. This operation may be continued for five minutes, and then the tube again tested with the current in the proper direction. By repeating this operation two or three times it is oftentimes possible to greatly improve a low vacuum tube. On the other hand, a tube with abnormally high vacuum may frequently be brought into good working order by placing in position on its stand, and cautiously heating, the glass bulb all over by means of the flame of a spirit lamp. The current should be turned off while this is being done. It is not easy to explain the cause of this beneficial result. Many experimenters have supposed that it depends on an alteration in the state of the internal vacuum of the tube. But the same result may be attained by surrounding the cathode end of the tube with a ring of imperfectly conducting matter,

such as cotton wool, or better with a ring of good conductor, such as gold paint or tinfoil. As the result of experiments made in this direction by Mr. J. Wimshurst, by Mr. Arthur Fish, and also by the Rev. T. E. Espin, it would appear that tubes that resist even the enormous pressure required to produce a 16-in. spark (equivalent to about 800,000 volts) in their natural condition may be made to fluoresce and give out X rays with a spark of 2 in. in length, equivalent to about 10,000 volts only. This band or ring of tinfoil should be attached over and in connection with the cathode end (the concave aluminium disc) of the tube, and may extend to about $\frac{1}{3}$ of the length of the bulb of the tube. It would, therefore, appear that this 'running up of the tube,' as this stubbornness to glow is sometimes called, is not due to any real alteration in the vacuum, or occlusion of the rarefied medium in the tube by the glass thereof, but to a kind of polarisation, or Leyden jar condition, between the inside and outside of the tube. In fact, it is often found that a tube which, although glowing brightly at the beginning of an experiment, gradually refuses to furnish X rays as the current continues to pass through it, will work perfectly if set aside for a short time. Another fact which seems to favour the view that this 'sulking' of the tube is due to polarisation is that if a small space be left between the tinfoil ring and the cathode loop sparks will be seen to pass across it. It is also sometimes possible to take a distinct shock, by turning off the current from a glowing tube, grasping the bulb near the anode with

one hand, and touching the cathode loop with the other.

It must not be inferred from the foregoing that it is recommended to select a tube that requires the addition of an outside coating to make it work, but simply that a tube, the vacuum of which is altogether too high to permit it to work with the current at our disposal, may be made to work by such an addition. It will be found that there is a 'best point' of vacuum suitable for every E.M.F., and the operator will do well in selecting a tube to make trial with his own coil, Wimshurst or Holtz machine. The tube should be of such a length (between anode and cathode loops) that there shall be no danger of the spark flying across on the outside of the tube, instead of traversing the inner vacuous space. In using the tube with the coil, and especially with a coil the secondary of which is wound with comparatively coarse[1] wire, it will be noticed that the platinum flat (the anode) becomes *red hot.* This is inconvenient in many ways. It may lead to a detaching of the glass stem from the contained platinum wire, which supports the anode. It also causes a smokiness of the glass of the tube, apparently by the volatilisation of the platinum. Owing to the very small ampèrage of the discharge of static machines (notwithstanding their high voltage) this heating of the anode *never* takes place with such; hence a break-down in the tube through this cause need never be apprehended when using machines of this kind. With a view to remedying this defect it has been tried with success by Cossor

[1] Hence giving a current of considerable ampèrage.

and others to 'back' the anode with a sheet of aluminium, a metal which, being an extremely good conductor and having a large capacity for heat, will bear a very considerable amount of electric 'bombardment' before it becomes red hot.

§ 62. For direct visual observation there is no doubt that the screen prepared with barium platinocyanide (see § 54) is preferable to all others known up to this date (November 1897).

The peculiar brilliancy of the ground renders the finer details much more distinctly visible, by contrast, than the dark grey of the calcium tungstate screen. Still, for all experimental work, and in cases where expense is a consideration, screens coated with the latter-mentioned salt will be found very satisfactory.

Whether the coil or a static machine be employed to excite the tube, it will be found extremely advantageous, in making delicate observations, to cut off all extraneous light from the surface of the screen by means of the hood or cover described at § 55. This, of course, is absolutely essential when observations have to be made in the day time or in a well-lighted room. It is also extremely convenient even when the room is darkened, because it entirely eliminates the flickering flashes, given either by the contact breaker of the coil or by the sparks passing between the spark-gap regulator of the Winshurst or other static machine employed, which flashes not only distract the observer's eye, but perceptibly affect the definition of the image on the screen. The body under observation should be placed as close to the tube as it

conveniently can without being in actual contact with it, and consistent with the rays emanating from the tube being able to embrace in their sphere of action all those portions which it is desired to examine at one time. The uncoated side of the screen should then be placed close against, and if possible in flat contact with, the body under examination. It is needless to remark that the coated side of the screen must face the observer's eye, since the cardboard mount is impervious to ordinary light, while virtually transparent to the X rays. So, if the cardboard surface faced the observer, although the X rays would be converted into light rays on impinging on the layer of fluorescent salt, yet, as these light rays are incapable of traversing the cardboard, no impression would be produced on the observer's eye. The surface of the screen, when in use, should not be covered with any medium whatever; but when set aside, to prevent abrasion, or soiling from deposited dust, it is well either to cover the surface of the frame with a thin piece of board of the same size, or else to slide the whole frame in a flat box made specially for the purpose. In many of the screens sent out by dealers the surface is covered with a thin sheet of transparent celluloid, and this is not objectionable so long as the surface of the celluloid remains clear and unscratched; but the surface of the celluloid is very soft, and soon becomes dulled with fine scratches, due to constant wiping. Celluloid is also highly electrical, and frequently, if wiped on the upper surface, exerts so powerful an attraction on the particles of the salt on the screen as to detach some of them from

the mount, and cause them to adhere to the under surface of the protecting celluloid sheet, with the result that a double and confusing image appears on the surface of the screen.

Our fig. 35 gives a very good idea of the arrangement of the different pieces of apparatus when employed for the examination of the chest, &c., while fig. 36 illustrates a convenient disposition of the patient, the observer, and the necessary equipments as employed in the French hospitals. These two latter are due to M. Gaston Seguy. Before leaving this portion of our subject it may be noted that although, when using static machines having only one pair of plates, the best results are obtained when the tube is excited by the discharges obtained from the outer coatings of the jars, as recommended at § 43, yet, when multiplate machines of large size are employed, a much steadier glow of the tube can be obtained by connecting it directly to the knobs of the Leyden jars. In this case the position of the tube must be reversed, since the inside, or knob coating, of the jar is in opposite electrical condition to the outside. Hence, under these conditions, the anode of the tube will be connected to the knob of that jar whose brush shows the *glow* discharge, while the cathode will be connected to the one displaying the *brush*. Lastly, if the machine is of very large size, and built up of many pairs of plates, such as the Wimshurst, mentioned at § 36, which consists of 12 pairs of plates 3 feet in diameter, or as the Holtz machine employed by Dr. Monell, consisting of eight plates, each 30 in. in diameter, the tube

works equally well without the jars. Of course in these latter cases the 'spark gap dischargers' must be re-

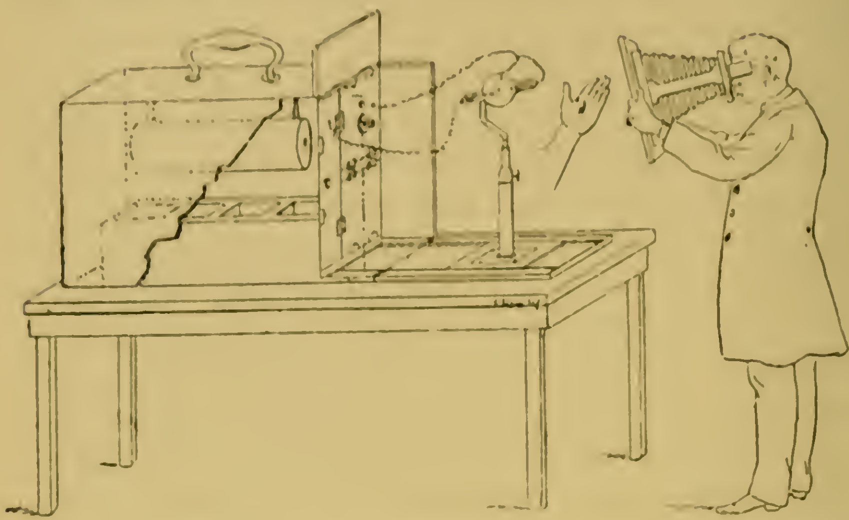

FIG. 35.—SEGUY'S ARRANGEMENT FOR VERTICAL EXAMINATION

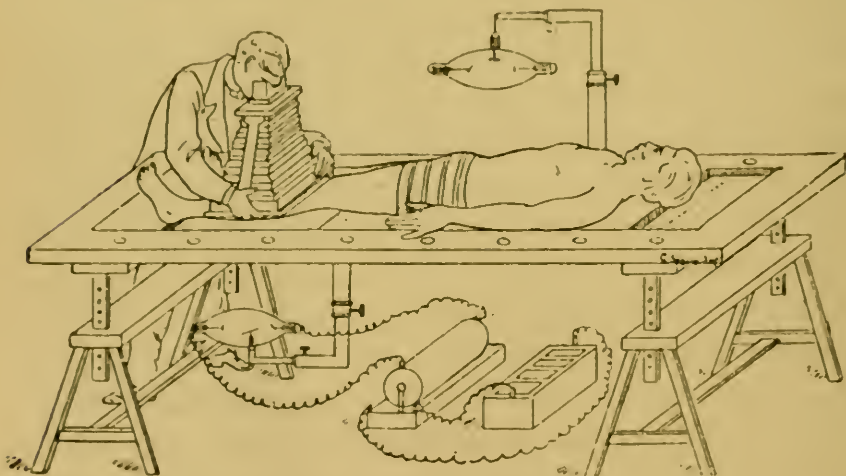

FIG. 36.—SEGUY'S ARRANGEMENT FOR HORIZONTAL EXAMINATION

moved. For the purpose of increasing the penetrative power of the X rays, coils of about 300 turns of No. 36 silk-covered copper wire may be inserted in the outer jar circuit, as mentioned at § 10. These coils should consist in a glass rod, about $\frac{3}{4}$ in. in diameter, 3 or 4 inches long, over which the wire is wound closely and without overlapping from end to end. Each coil should be soaked in melted paraffin wax till no more bubbles arise, then taken out and allowed to cool. When cold the coils are arranged horizontally on a little ebonite base, and a small well-polished brass ball, about $\frac{1}{2}$ in. in diameter, soldered to the two free ends of the helix. These coils can then be arranged in the circuit, with gaps between them, as directed at § 10. There is no doubt that these interrupters do alter the oscillation rate of the discharge, and heighten the effects of the tube; but their employment is attended with the disadvantage that the lighting of the tube becomes to a certain extent intermittent, or 'flashing,' instead of 'glowing.' This to the eye is fatiguing; but for actual radiographic work it makes no difference whatever.

§ 63. We can now pass to the second branch of our subject—namely, the production of photographs by means of the X rays. It is not proposed here to write a treatise on photography, and we would advise any one who desires to produce good results with the tube to take a few lessons in ordinary photography with the camera before he attempts to take a radiograph. The operations necessary to the production of a photographic picture are, first, the preparation of a plate or other surface

with a substance sensitive to light or other rays; second, the exposure of this plate to the action of light; third, the development of the image (usually invisible) produced on the surface by the action of light; fourth, the fixation of the resulting image, which process consists in the removal of that portion of the sensitive salt which has not been affected by light or by the developer, but which if left on the plate would darken and render it unstable; fifth, the reproduction of this image, which is 'negative,' or has its lights and shades the reverse to what they are in Nature, on a second sensitive surface; this operation is technically known as 'printing.' As prepared plates, films, and papers are to be procured so good and so cheaply as to render it absolutely a waste of time for any one to attempt to make them himself (except, indeed, for the purpose of trying experiments), no description of the mode of preparation is here given. It is only needful here to mention that the sensitive surface, be it spread on glass, celluloid, or paper, consists virtually of a mixture of bromide and iodide of silver, emulsified with gelatine, and allowed to set and dry on the support. The plates, &c., being extremely sensitive to the action of *ordinary* light, must never be exposed to its action; and all operations must be conducted in a room from which all daylight is most carefully excluded, and lighted only by means of artificial light, which, by the aid of a suitable ruby-coloured glass screen, or cherry-red lining, entirely surrounding the source of light, emits only rays of a yellow red type, that do not affect the plate. Suitable lanterns for this purpose are sold by all photographic dealers. The operator *must* have sufficient light

(of this colour) to work by comfortably; but he must not expose his plates, even to this light, more than is absolutely necessary. To expose a plate he will proceed (as directed at §§ 43, 44) to place a plate in the inner yellow envelope of one of Tylar's light-tight bags, of suitable size, while in the darkened room. Before placing the plate in the bag he will do well to remove any dust there may be on the prepared side, by sweeping over the surface lightly with a wide, soft camel-hair brush, kept clean and specially for this purpose only. The plate (to prevent any irregularity of action) should be placed with its prepared surface against the *seamless* side of both inner and outer bags; and to prevent any stray rays of light getting in it is well to insert the yellow bag into the outer black bag, flap end first. The stock box containing the plates, &c., should be closed and put away before opening the door of the dark room. The operator now proceeds to expose the plate. For this purpose, having connected up the tube to the coil, he turns the stand and tube into a convenient position to throw the cathode or X rays, reflected by the anode, on the surface of the body to be radiographed. Under this he places the plate contained in the Tylar's bag, *sensitive side uppermost*. The distance between the tube and the object depends a great deal on the nature of the object, on the spark length required by the tube, and on the rapidity with which it is desired to produce the picture. Working with a 3-in. spark tube, taking about 150,000 volts, on *thin* objects—say, from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. thick—a distance of about $4\frac{1}{2}$ in. to 5 in. may be allowed between the tube and the plate, and a fair result will be obtained with

exposures varying from 1 to 2 minutes. But if the object be thick—say, the forearm or ankle—although it is possible to get a picture with the tube so near, yet the image is magnified and distorted somewhat. Removing the tube to a greater distance remedies these defects, but at the same time lengthens the exposure, directly as the square of the distance; *e.g.* a given object, which, with a given tube, would require an exposure of 1 minute to produce a satisfactory picture at 4 in. distance, would take 4 minutes' exposure to give a like result at 8 in. distance. Hence this general rule can be formulated: For a given length of exposure, with thin objects, a short spark tube, at a short distance, may be employed; for thick objects and longer distances long spark tubes *must* be used. The plate, tube, and object being duly placed in position, care of course being taken in the case of a living subject that the portion to be radiographed is so supported, resting on the plate in the Tylar's bag, as to preclude all possibility of motion during the exposure, the battery current is turned on the coil with all the precautions mentioned at § 59, and the tube allowed to glow for the desired length of time.

As previously remarked, there is really so little difference between the results obtainable with the different brands of plates in the market that it is an invidious task to mention any one in preference to others. There is one point, however, which may be mentioned, without prejudice to any particular maker's productions, and that is that it by no means follows that because a given make of plates is highly sensitive

to ordinary light it should rank high in sensitiveness to the X rays. On the contrary, it may be broadly stated that, with one notable exception, the 'extra rapid' types of dry plates are less suitable for X ray work than the 'ordinary' and 'medium' rapidity. It is extremely difficult to make a fair and satisfactory comparison of different brands of plates, partly because nearly every maker advises the use of a somewhat different developer, and the operator naturally requires a little practice before he can master the peculiarities of each. Then, again, for a fair trial the conditions of exposure must be absolutely identical, and this is only to be obtained by making up a composite plate of many strips of different brands. And the development of these different strips, each one with its own special developer, does not quite satisfy the enquiring mind as to whether one of the other apparently inferior strips would or would not have given equal results if it had been developed with the developer employed on the most successful strips. For this reason the author has found it advisable to use in the trials which he has made only one standard developer. It must, therefore, be evident that it is quite possible--nay, highly probable—that with other developers the apparent sensitiveness to X rays would come out in different order. Three brands of plates have given great general satisfaction, and these are Cadett's 'Lightning,' Edwards's 'Cathodal,' and Thomas's 'A1.' Sandell's likewise have given excellent results, as also the 'Imperial' Röntgen. With the Ilford plates the 'extra rapid' were not so efficient as the 'ordinary.' The only ones in which the

'extra rapid' show a distinct advantage over the slower plates are those by Messrs. Cadett and Neall. As a matter of personal equation, and with the developer which he usually employs, the author gives the preference, for direct radiographic work without the use of the screen, to the 'Lightning' brand; but he has seen results equally good produced on Edwards's 'Cathodal' plates and on Thomas's 'A1.' As a little guide to the exposure, using either of these brands of plates in conjunction with a good 6-in. spark 'focus' tube at a distance of about 8 in. from the surface of the plate, an adult hand should give a good picture in about ninety seconds, the wrist in about five minutes, the elbow in from fifteen to twenty minutes, the knee in about half an hour. The shoulder, the thorax and the hip joint may take half to three-quarters of an hour, according to the thickness the rays have to traverse. When a good static machine is employed instead of a coil these exposures are considerably shortened, and Dr. Monell records that he has been able with his machine to produce a negative, showing with considerable distinctness the upper portion of the spinal column of a man aged thirty, with ninety seconds' exposure, the distance between the tube and the plate being 16½ in. In the case of thin metallic objects, where it is not desired to show any detail of internal structure, it will be found that two or three seconds will suffice to produce an impression, and in the case of a static machine being employed a single flash traversing the tube will, if this latter be in good working order, give a printable negative. The exposure being com-

pleted, the operator shuts down the current from his coil, or other means of exciting the tube, and returns with the Tylar's bag to the dark room. He will carefully close the door and see that no light can gain access to the plate, except through the ruby-coloured medium of his lantern. He then places in readiness two flat dishes (each of which must be kept for its special solution and nothing else), in the first of which he pours out a sufficiency of developing solution to entirely cover the plate, and into the second the fixing solution. The developing solution may either be compounded, as below—viz.

Stock Solution

Pyrogallic acid	1 oz. avd.
Ammonium bromide	½ oz. ,,
Potass metabisulphite	1 oz. ,,

Distilled water to make altogether 7 oz. 3 drs. fluid.

Dissolve the metabisulphite and bromide in part of the distilled water before adding the pyrogallic acid.

A. Stock solution 1 oz., distilled water to make up 20 oz. = 1 pt.

B. Ammonia (·880) 2½ drs., distilled water to make up 20 oz.

For use equal parts of A and B are to be mixed together—

or a developer made according to the following recipe, and containing *metol*, may be employed :—

No. 1

Metol	120 gr.
Sulphite of soda	2 oz.
Bromide of potassium	120 gr.
Water to make up	20 oz.

No. 2

Carbonate of soda crystals	2 oz.
Water to make up	20 oz.

In use equal parts of Nos. 1 and 2 are mixed together, and water equal to three times the bulk of the resulting mixture is added. Should the weather be very cold the quantity of water may be halved; this is also true in the case where the exposure has been short. The ferrous oxalate developer, for which we gave the formula at § 44, will also be found to give excellent results. But we strongly recommend the operator to make up his developer in accordance with the directions given by the makers of the particular brand of plate which he is using, and above all things to take up and adhere to one make of plate and one developer until he has mastered their peculiarities. No good accrues from continually changing plates, or mixing up developers according to different recipes. If failures do occur (and when will they not?) they are more likely to depend on a want of skill on the part of the operator than upon any faults inherent to the plates or the developers. The plate is now removed from the bag, and placed, sensitive side upwards, in the dish containing the developer, and this latter immediately rocked, to cause the developer to flow equally over the plate, and kept rocking in order to present fresh portions of the developer to the surface of the plate. Little by little the image will appear, and the creamy-looking film will gradually darken in certain places (where acted on by the rays), while those portions protected by bone, metal, or other bodies more or less opaque to the rays will not change colour. To judge when the development has been carried to the right point is by no means an easy task for the beginner; but

FIG. 37.—UNDER-EXPOSED NEGATIVE.

FIG. 38.—PROPERLY EXPOSED NEGATIVE.

FIG. 39.—OVER-EXPOSED NEGATIVE.

it may be taken as a general rule that, when the dark portions of the image show through the film, so as to be visible by reflected light from the back (the glass or plain side) of the plate,[1] the photograph is sufficiently developed. If the exposure has been insufficient the picture develops slowly; the parts acted on by the light become very black, and the shaded portions show absolutely no detail, so that the resulting effect is that of a hard-outlined silhouette (fig. 37). A properly exposed picture does not develop very quickly, generally begins to show the outlines in from thirty seconds to a minute, and may require from fifteen to twenty minutes' development to bring out every detail (fig. 38). As a matter of fact, it is not well to use a developer of such a strength that it causes the image to flash out quickly. The best pictures are certainly produced with a comparatively slow development (see latter end of § 44). If the picture has been over-exposed (see fig. 39) the image appears very quickly, and if left to itself would become grey all over, and the result would be a picture so flat and so wanting in contrast as to be almost useless. But if immediately on the sudden appearance of the image the plate be removed from the developing solution and thoroughly washed, and then put into a similar solution which has been diluted with its own bulk of water, and to which a few drops of a 10 per cent. solution of bromide of potassium have been added, the picture may be saved. The exact amount is not of much moment, but the

[1] This will not be visible if very thickly coated or double-coated plates are used; but such are not recommended for radiography.

greater the over-exposure the larger may be the proportion of added bromide.

In the normally exposed picture a very considerable amount of detail will be seen all over the image. In the case of a hand, for example, the folds of the skin between the fingers, the texture of the nails, the spongy terminations of the finger bones, the epiphyses of the phalanges, and in a young hand the distinct divisions between these latter are well shown.

No part of the plate, except that which is not protected by the hand, will be entirely blackened, while on the other hand none will be left quite white, except that lying directly under some metallic object, such as a ring, a sleeve-link, or a shot. When the picture has been sufficiently developed, the plate must be withdrawn from the developing solution, and well washed in a stream of water. For this purpose the dark room should be furnished with a sink and water tap in connection with a cistern or main. Failing these, the plate must be washed in several changes of water, in a flat dish, taking care, of course, that no light, except that from the ruby lantern, gets access to it, until all trace of the developer is removed. The plate should then be placed in the dish containing the fixing solution, face upwards. Enough fixing solution should be contained in this dish to cover entirely the plate, to the depth of at least a quarter of an inch. The best recipe for the fixing solution is :—

Hyposulphite of soda	4 oz.
Water	1 pt.

Shortly after immersion into this solution, it will be noticed that the milky whiteness of the unaffected portions of the plate disappears ; this is caused by the dissolution of the unaltered silver salts in the fixing solution, which, however, leaves untouched those portions which have been acted on by light and by the developer. Little by little the whole of the unaffected portions are dissolved out, and the image will be then seen to consist of more or less clear glass with a grey or brownish image on a darker ground. The plate should be left in the fixing solution for at least five minutes after all milkiness (best seen from the back of the plate) has disappeared, to ensure perfect fixation. Light may now be admitted in the dark room, the fixed plate removed from the fixing solution, and washed in abundance of running water, until perfectly free from any trace of hyposulphite. The quickest way of ascertaining whether the plate has been sufficiently washed is to allow a drop to trickle from the bottom corner of the plate on the tongue. Should any appreciable amount of hyposulphite be left in the film, it will betray its presence by an unmistakably unpleasant metallic and sweetish taste. The operators must be particularly careful to wash away every trace of fixing solution, as if any be left in the film it will eventually destroy the picture, and surely stain the paper which is used in the after-printing process. The picture, having been carefully washed, is reared up to dry in any convenient place, free from dust. A strip of blotting paper along the lower edge, for the plate to rest on, will

facilitate matters. The spot chosen for the drying of the plates should be dry, and may be traversed by currents of air, but artificial heat, or indeed any heat above 70° F., should be avoided, because the damp gelatine surface readily softens and melts at a higher temperature, when of course the picture would be irretrievably spoiled. Should it be deemed advisable, for the sake of shortening the time of exposure, to use a screen in conjunction with the plate, the *modus operandi* will be, in all respects but one, precisely the same. The exception is that the inner receptacle (the yellow envelope) of the Tylar's bag must previously be fitted with a celluloid screen (coated on one side with the fluorescent salt chosen) which is just contained in the bag. This screen must be placed in the bag with its coated side facing the seamless half of the bag; and to prevent its moving about, or being pulled out of the bag during the insertion or extraction of the sensitive plate, and also to avoid any accidental abrasion of the surface of the latter by the action of particles detached from the surface of the screen, it will be advisable to run a narrow line of glue round the edges of the screen, and thus glue it bodily against the inside of the seamless portion of the yellow envelope. For this purpose no screen has given the author such general satisfaction as that coated with calcium tungstate. Even when employed with ordinary plates, it certainly shortens the exposure 50 per cent.; and if the plates are previously 'orthochromatised' by staining with erythrosine, the exposure may be diminished 75 per cent. All photographic dealers

supply such plates, and if the operator specifies in ordering that he requires plates stained specially sensitive to pale yellowish green light, he will have no difficulty in obtaining them. There is one disadvantage connected with the use of the screen in obtaining radiographic pictures which must be adverted to here, and that is that the minute crystals with which the surface of the screen is coated reflect the light which they emit under the influence of the X rays in many directions. The result is that the outlines of the image are not quite so crisp and sharp as they are when no screen is employed ; also a slight but distinct *granularity* is imparted to the image. The coarser the crystals on the screen, the more noticeable is this effect, hence the ordinary brands of barium platinocyanide, though exquisite for direct-vision work, are not so well adapted for photographic purposes. If barium platinocyanide or uranium fluoride are used on the screen, orthochromatic plates *must* be employed in conjunction with them, otherwise the yellowish fluorescence of these salts, so far from shortening the exposure, will actually lengthen it. With the calcium tungstate screen (whether in conjunction with calcium sulphide or alone) it is not so imperative to employ orthochromatic plates ; but even in this case their employment is a decided gain in point of time.

The negative being quite dry, the careful operator will proceed to protect its surface by giving it a coat of suitable 'negative varnish,' which he will procure from any photographic dealer. This he will dry

thoroughly before a clear fire. He will then place the negative face upwards in the printing frame, and over it lay a sheet of sensitised paper, say for example P.O.P. Over this he places the hinged back of the frame, which he fastens down by means of the spring clips. The frame is then taken to any spot where clear unobscured light from the sky can fall upon the surface of the plate. Unless the negative is very dense indeed, it will be better not to expose it to the full glare of the sun, but to choose a spot which, without being shaded, does not receive the sun's direct rays. According to the density of the negative, the operator will leave the frame exposed to light for a period which may vary from two and a half to twenty minutes or even half an hour. To judge of the progress that the picture is making in printing, the operator will remove the frame after, say, two minutes' exposure to light, and, withdrawing to a room free from the direct rays of the sun, will unfasten one only of the side springs of the printing frame, and lifting up one half of the hinged back will examine (with as much expedition as possible, to prevent the paper from being affected even by diffused light) the resulting print. The printing must be carried to such a point that the picture *appears much darker* than it is intended it should remain, as the image loses a great deal in intensity during the after processes of toning and fixing. The printing having been carried to a suitable extent, the resulting print (or prints, if several have been done) is immersed into water contained in a suitable flat porcelain washing dish, and allowed to

stand under a tap giving a fine stream of running water, until all milkiness disappears. When this is the case, the print should be at once removed from the water, by means of a suitable pair of horn clips, and immersed in the following *toning* solution, which *must* have been made up the day before :—

TONING SOLUTION

Chloride of gold	1 gr.
Acetate of soda	30 gr.
Distilled water	5 oz.

Here the print must remain, with constant moving about to prevent unequal toning, until the desired colour has been attained. It is needless to remark that the print must on no account be touched with the fingers, or allowed to come into contact with any metallic body, or any dirt of any description, otherwise it will surely be stained. After toning sufficiently, the print is removed from the gold solution, washed for a few seconds in running water, and then immersed in a fixing solution consisting of :—

Hyposulphite of soda	5 oz.
Water	1 pt.

Care must be taken to avoid air bubbles, and to see that the print is thoroughly covered by the solution. It will be noticed that the print when first immersed in the fixing solution changes colour, losing somewhat of its purplish tint, and going more of a ruddy tone ; but if the printing and toning have been correct, the purplish

tone returns after a short interval. The print should be left in this solution for not less than ten minutes, being moved about in the liquid from time to time. When the fixation is complete—and this may be pretty accurately judged by holding the picture between the eye and the light, when the paper should show an even texture throughout, without having any 'measly' spots or patches—the print should be thrown into a dish of water and allowed to wash therein for about twelve hours, in a running stream of water. Thorough washing is essential to the permanency of the print; if any hyposulphite be left in the paper, the picture will turn yellowish and gradually fade away. None of the above operations are difficult, almost any one can master the details; the great essentials to success in photography are perfect cleanliness of all the apparatus employed, never allowing the solution to get mixed or to touch the plates, dishes, or paper other than at the right time and places; neatness, and a strict observance of all the precautions necessary to the avoidance of stray white light getting at the plates. In this latter connection it must be noted that the sensitive plates, even though enclosed in the light-tight boxes in which they are usually sent out, must not be allowed to remain in the room in which the coil, the Wimshurst, &c., and tubes are usually experimented with; otherwise the X rays will certainly penetrate the cases, and 'fog' the plates. Even if kept in an adjoining room, it will be well for the sake of absolute security to keep the plate boxes in an outer metallic case, such as a tin trunk. The metal, being practically impervious to

the X rays, will effectually shield the plates from their action.

The use of flexible films instead of rigid glass has been advocated by some operators; the author has not had personal experience with either paper or celluloid films, but the following remarks, condensed from an article in the 'Kodak News' for March 1897, may be of service in indicating the advantages which may accrue under certain circumstances from the use of a flexible support for the sensitive film, such as we find in 'bromide papers,' &c. So long as we are dealing with a flat object which can be brought closely and flatly into apposition with the sensitive surface, a flat and rigid glass plate will answer our purpose, but as soon as we have to deal with a rounded object, which cannot fulfil this condition, we must lose sharpness at some part or other of the image. It must be evident, then, that in this respect at least paper has a marked advantage over glass, as it can be bent to suit the contour of the object. Again, glass is known to present considerable opposition to the X rays, hence the radiation cannot be projected through one glass plate to another below, consequently in practice only one radiographic image can be obtained at one time on glass plates. Paper on the other hand presents practically no opposition to the passage of the rays, so that as many as 200 impressions have been obtained at one operation by superimposing as many sheets of Eastman's X ray paper, and placing them in a suitable receptacle under the object to be radiographed. In this case, of course, the more opaque portions, as metal, brass, &c.,

came out white on a dark ground. This is no disadvantage. The time required for exposure when using the above-named paper is practically the same as that required for ordinary plates, the writer of the above notice having obtained good pictures of the hand at 6 in. from the tube, in one minute, the developer used being the ordinary 'amidol' solution. At the end of Chapter X. will be found a few radiographs which will enable the student to judge of the capabilities of radiography in detecting flaws in materials, differentiating bodies, and localising disease, malformation of bones, &c., &c.

CHAPTER X

THEORETICAL CONSIDERATIONS

§ 64. Knowing so little as we do of the real nature of electricity, it is extremely difficult to theorise on, or to attempt to explain in a satisfactory manner, the causes of the results we have just studied, and which appear to depend upon the passage of electricity through extremely high vacua, or perhaps, to speak more correctly, upon the resistance offered by high vacua to the passage of the electric flow. From the classical experiments made by Professor Crookes several years ago on the motion imparted to the dissociated atoms or molecules of gas in a so-called high vacuum by the action of light, now well known as the phenomenon of radiant matter, it would appear that a kind of rhythmical motion takes place under the influence and in the direction of the lines of energy applied,[1] and that this motion gives rise to a kind of molecular bombardment of the sides of the tube, &c., enclosing the vacuous space, or of any body therein contained. This effect is well seen in the little movable vanes of Crookes's radiometer, the blackened

[1] The energy may be either in the form of light, heat, or electricity.

surfaces of which get heated under the effect of the bombardment, and are themselves beaten back by the reaction of the rebounding molecules. One of the theories held as to the nature of the cathode rays is that they are due to particles of highly rarefied gas, carrying charges of negative electricity, and moving with great velocities which they have acquired as they travelled through the intense electric field which exists in the neighbourhood of the negative electrode. The phosphorescence of the glass is on this view produced by the impact of these rapidly moving charged particles; though whether it is produced by the mechanical violence of the impact, or whether it is due to an electro-magnetic impulse set up by the sudden reversal of the velocity of the negatively charged particle—whether, in fact, it is due to mechanical or electrical causes—is an open question. This view of the constitution of the cathode rays explains in a simple way the deflection of those rays in a magnetic field, and it has received strong confirmation from the results of an experiment made by Perrin. Perrin placed inside the exhausted tube a cylindrical metal vessel with a small hole in it, and connected this cylinder with the leaves of a gold-leaf electroscope. The cathode rays could, by means of a magnet, be guided so as either to pass into the cylinder through the aperture or be turned quite away from it.

Perrin found that when the cathode rays passed into the cylinder the gold-leaf of the electroscope diverged, and had a negative charge, showing that the bundle of cathode rays enclosed by the cylinder had a charge of

negative electricity. Crookes had many years ago exposed a disc connected with a gold-leaf electroscope to the bombardment of the cathode rays, and found that the disc received a slight positive charge; with this arrangement, however, the charged particles had to give up their charges to the disc if the gold-leaves of the electroscope were to be affected, and we know that it is extremely difficult, if not impossible, to get electricity out of a charged gas merely by bringing the gas in contact with a metal. Lord Kelvin's electric strainers are an example of this. It is a feature of Perrin's experiment that, since it only acts by induction, the indications of the electroscope are independent of the communication of the charges of electricity from the gas to the cylinder, and, since the cathode rays fall on the inside of the cylinder, the electroscope would not be affected even if there were such an effect as is produced when ultra-violet light falls upon the surface of an electro-negative metal, when the metal acquires a positive charge. Since any such process cannot affect the total amount of electricity inside the cylinder, it will not affect the gold-leaves of the electroscope; in fact, Perrin's experiments prove that the cathode rays carry a charge of negative electricity. The author is not quite satisfied that the deduction contained in the last sentence (by Professor J. J. Thomson) is quite justified by the premisses. While fully admitting that the results are due purely to induction (which is substantiated by the experiment noted at § 8), it is not quite so sure that the interposition of media of different specific inductive capacities between the tube and the

electroscope may not influence and modify the result. It must be noted that the Lenard or cathode rays are by many not considered identical with the Röntgen rays. The cathode rays can be emitted when the vacuum is as low as that represented by $\frac{1}{10000}$ of the ordinary atmospheric pressure, while to ensure the production of the Röntgen or X rays the vacuum must be carried much farther. The cathode or Lenard rays are readily deflected by a magnet; not so the true X rays.

But this divergence may depend more upon an alteration in vibration rate than upon any essential difference in the nature of the rays themselves, just in the same way that the invisible ultra-violet vibrations take up another vibration rate, and become visible as *blue light* on impinging upon a surface of quinine in solution. In one of Lenard's first experiments in this direction he found that his 'cathode' rays, even after traversing a thin aluminium screen, were capable of affecting and causing to phosphoresce (fluoresce?) that euphoniously named body 'pentadecylparatolylketone,' and of giving a distinct photographic image through aluminium and through quartz. He thus arrived at two of the most striking results obtainable from the Röntgen rays proper. Among others who hold the above view in its most advanced form is M. Tesla.[1] He states 'that the electrical conditions within the tube from which the rays issue produce absolute motion in the particles.' He avers that he can feel the effects of these particles striking against his eye, and has noted the

[1] *English Mechanic.*

sensation they produce when they come in contact with his brain. He says: 'There is little doubt now that a cathodic stream within a bulb is composed of small particles of matter thrown off at great velocity from the electrode. The velocity attained can be estimated, and fully accounts for the mechanical and heating effects produced by the impact against the wall or obstacle opposed to the bulb. It is moreover an accepted view that the projected lumps of matter are like innumerable infinitesimal bullets. It can be shown that the velocity of the stream may be as much as 100 kilomètres per second, or even more. And matter moving with such great velocity must surely penetrate great thicknesses of the obstruction in its path, if the laws of mechanical impact are at all applicable to the cathodic stream. I have so much familiarised myself with this view that if I had no experimental evidence I would not doubt that some matter is projected through the thin wall of a vacuum tube. The exit from the latter is, however, the more likely to occur, as the lumps of matter must be shattered into particles much smaller still by the impact. From my experiments it appears that the lumps or molecules are indeed shattered into fragments or constituents so small as to make them lose entirely some of the physical properties which they possessed before the impact. The matter composing the cathode stream is reduced to matter of some primary form not heretofore known, as such velocities and such violent impacts have probably never been studied or even attained, before these extraordinary manifestations were observed. The

important fact early pointed out by Röntgen, and confirmed by subsequent researches—namely, that the opacity of a body to these rays is as a general rule directly proportionate to its density, cannot be explained as satisfactorily by any other assumption than that of the rays being streams of matter, in which case such simple relation between opacity and density would necessarily exist.'

§ 65. The other view held as to the constitution of the cathode rays is that they are *waves* in the *ether*. It must be admitted that, with the highly hypothetical and varying properties attributed to the ether, this is by no means a satisfactory explanation. Premising that few physicists agree as to the precise attributes of 'ether,' the following definition, given by Professor Oliver Lodge, may be of service in assisting the comprehension of what follows. 'Ether, a continuous medium pervading all space and all matter, but possessed of inertia; the medium by means of which energy and motion are transmitted from atom to atom.' Then again Professor Lodge asks the question,[1] 'Is the ether electricity then? Positive and negative electricity make up ether.' The chief reason adduced for supposing that the cathode rays are a species of wave motion is afforded by Lenard's discovery that when the cathode rays in a vacuum tube fall upon a thin aluminium window in the tube, rays having similar properties are observed on the side of the window at the exterior of the tube; this is readily explained on the hypothesis that the waves are a species

[1] *Modern Views of Electricity.*

of wave motion to which the window is partially transparent, while it is not very likely that particles of gas within the tube would force their way through a piece of metal. But up to the present time all efforts to obtain any movement in 'ether' have failed. Professor J. J. Thomson, speaking on this subject at the British Association, adverts to this fact in the following words :—

> You are all doubtless acquainted with the heroic attempts made by Professor Lodge to set the ether in motion, and how successfully the ether resisted them. It seems to be conclusively proved that a solid body in motion does not set in motion the ether at an appreciable distance outside it. We have, at the Cavendish Laboratory, using Professor Lodge's arrangement of interference fringes, made some experiments to see if we could detect any movement of the ether in the neighbourhood of an electric vibrator, using the spark which starts the vibration as the source of light. The movement of the ether, should it exist, will be oscillatory, and with an undamped vibrator the average velocity would be zero; we used, therefore, a heavily damped vibrator, the average velocity of which might be expected to be finite. The experiments are not complete, but so far the results have been entirely negative.

Sir George Stokes originally held the opinion that the Röntgen rays were transverse waves. But the absence of any reliable evidence of the diffraction of these rays has induced him to abandon this view. He does not, however, accept Lenard's theory that the Röntgen rays differ from the Lenard rays in degree only. He adopts the theory that the cathode rays are a stream of flying particles. The bombardment of the anticathode (the anodal plate) by the cathode rays produces a rapid series of non-periodic disturbances, which are propagated

from it in every direction. Sir George Stokes has satisfied himself by mathematical investigation that such non-periodic disturbance would not exhibit diffraction phenomena. The theory of diffraction shows that a succession of timed periodic impulses is necessary for the production of such. He explains the production and propagation of Lenard's rays in a vacuum, by the analogy of a copper plate placed in a solution of sulphate of copper, through which a current is passing. As is well known, the copper molecules appear in this case to pass through the copper plate, but the explanation in the terms of Grotthuss' theory is simple and well known.

§ 66. Leaving the reader to decide between the merits of these two theories, we present him with another 'working hypothesis,' which, although it may not turn out eventually to be correct, at least so far connects the various phenomena together as to enable the student to grasp the known facts, and to be able to relegate into their proper places new ones which may arise.

On this view it is supposed that those manifestations which were formerly known under the name of 'imponderables'—to wit, heat, light, and electricity—are one and all simply modes of motion in the molecules (or perhaps atoms) of matter. What this motion is we know not, how produced *ab origine* is likewise a mystery to us; for in Nature we can only become cognisant of two things—viz., matter and motion, the former of which we imagine we know something of, while of the latter, except in its manifestation in matter, we know nothing, except that we can neither produce it nor destroy it. Now the chief

difference, as far as we can judge, between the three 'imponderables' above mentioned lies in the vibration or oscillation rate set up in the atoms or molecules of the bodies manifesting them. Something also may depend on the direction of these vibrations, and whether they are complicated by the simultaneous presence of rotary motion of the molecules or not. For instance, it is known that the yellow light given out by sodium requires the sodium atom to make five hundred million vibrations in the millionth part of a second. A vibration rate of about four hundred millions in the millionth of a second will cause carbon to give out red light and *heat*, while, to push the analogy still further, with masses instead of molecules or atoms, a vibration rate of 512 vibrations per second will cause a stretched string or a column of air to emit that sound which we recognise as the C one octave above the middle of the pianoforte. The lengths as well as the vibration rates vary according to circumstances; thus a condenser of 1 microfarad capacity, discharging through a coil having a self-induction of 1 secohm, will give rise to waves 1,200 miles long, and the rate of its oscillation is 157 complete swings per second.[1] By altering the length of the circuit, or by introducing self-induction coils, we can shorten these waves and quicken the oscillation.

Taking it for granted, then, that by altering the vibration rate of matter we can cause it to manifest either heat, light, or electrical phenomena, it will not be difficult to understand that when a molecular disturbance is set

[1] Lodge, *Modern Views of Electricity.*

up by a difference of potential in a tube containing dry air or carbon dioxide at the usual pressure, the molecules will take up a given oscillation rate, with a certain length of wave, and that the molecules being closely packed the waves will be short enough to affect the eye as ordinary light. Other phenomena may and do actually accompany this manifestation of light, as, for example, magnetisation of iron or steel placed at right angles to the line of molecular flow, and this through substances which are absolutely opaque to the rays of light. If the air in the tube be rarefied by exhausting the tube, a point is soon reached at which the molecules, being freer to move without collision, give forth light of less intensity—*id est*, of such wave length as not to be so readily appreciated by the human eye. When the exhaustion has reached a certain point of high vacuum, very little light is perceptible. This means that few or no waves having a vibration rate lying between 400,000,000 and 700,000,000 per second (the limits of ordinary vision) are set up. But the waves *are* there, as can be proved by the possibility of taking a photograph with them through a sheet of aluminium, or by reconverting them into light by allowing them to fall on a suitable fluorescent surface, which, either by altering the vibration rate or the wave length, or both, restores to them the power of affecting the retina. At this point of exhaustion the wave stream constitutes the *cathode* rays. On continuing still further the exhaustions, the molecules in the tube find yet less obstruction to their motion, hence probably the velocity is greater while the wave length may be longer or shorter according

to the condition of the circuit. At any rate, very little light *as such* is now given off, and what is seen is probably due to the vibration set up in the molecules of the glass tube itself. At this point we have the production of X rays proper, accompanied no doubt by others, such as some light, some heat, and a considerable display of induction. To explain the possibility of these waves being able to act on bodies *outside* the tube, it is by no means necessary to fall back on 'the ether.' It will be quite sufficient to remember that if we ring a given note loudly near a wine glass we can cause it to enter into vibration so as to give out the same note, or that if we strike a suspended sheet of iron on one side we can cause the air on the other side to enter into vibrations corresponding to those imparted to the sheet, to understand that the glass tube may enter into a similar rate of vibration as the moving molecules, and may impart to the surrounding air a rate of vibration and a wave length of corresponding value. Here we must pause to consider the meaning of *transparency* when used in relation to these different waves. In speaking of light we have no difficulty in understanding it; *then* it simply means the property of allowing rays of a certain length and rapidity to pass through and affect our eye.

But it does not follow that because a body is opaque to the vibration we call light, that it shall be so to others, or *vice versa*. For instance, alum is fairly transparent to light waves, while it permits the passage of only 0·12 of the heat waves. On the other hand a solution of iodine in carbon bisulphide, which is almost opaque to

light, allows heat to pass very freely. So, again, a sheet of metal is virtually opaque to electrical waves, while a sheet of ebonite allows induction to take place through it freely. A sheet of iron, a block of hard wood will easily transmit the vibration rate we call sound; while both these bodies are opaque to ordinary light. It will not be surprising, then, to find that many bodies, such as wood, leather, paper, ebonite, &c., are easily traversed by the particular wave length and vibration rate set up by the electric flow in the highly exhausted tube employed for the production of the X rays, and thence either by induction or else directly by the rhythmic movement of the walls of the tube itself in obedience to the impulses imparted to them, more especially in the direction of the lines of reflection from the anode, to these surrounding bodies. The photographic effects of these rays may or may not be purely inductive electrical effects (see § 4). In the former case we should expect the rays to act most powerfully when falling on the surface of a body of high specific inductive capacity, as, for example, ebonite; while very little effect should be set up if a body of poor inductive capacity, as a metal, were interposed (this is actually the case). But in all probability other vibration rates accompany the electric ones. The effect is not so immediately perceptible when we attempt to recognise this new order of transparency by the eye alone, although it has been recently shown by Professor Brandes that the retina of the normal eye is somewhat sensitive to the Röntgen rays, even without a fluorescent screen, and when the eye itself is shielded by a sheet of

aluminium. But directly we reconvert these vibrations, which have traversed flesh, leather, bricks, wooden billets, &c., into ordinary light by altering their vibration rates (as we can do by means of suitable fluorescent bodies), we become cognisant of the fact that there are very few bodies indeed which are not transparent to suitable vibration rates. And, in fact, it is now an acknowledged fact that the so-called X rays are not homogeneous, but are of many kinds, differing in penetrative power, this quality depending first on the induction in the circuit, second the state of the vacuum, third the form of the tube, and fourth the nature of the emitting surface: conditions which can and do largely influence the wave length and the vibration rate of the moving molecules.

§ 67. Although it is practically impossible to render justice with a print from a block, to the delicacy and fineness of detail that can be obtained in a good radiograph, we trust that the accompanying reproductions may prove acceptable, as showing, in some small degree, the capabilities of radiography in the hands of medical men and others.

Fig. 40 shows the appearance presented when the human chest is viewed through the fluoroscope (illustrated at fig. 35), actuated by a good tube. This picture is due to M. Gaston Seguy, and was taken with a bianodic tube.

Fig. 41 is a good example of the ease with which shot, or other metallic bodies, embedded in the flesh, can be located. The coat sleeve and cuff, being virtually

transparent to the X rays, have left little or no indication of their presence; but the sleeve links, being metallic, have given a strong impression. The author is indebted to Messrs. R. W. Thomas for permission to reproduce this fine picture. It was taken on one of their 'A 1' plates with an exposure of two minutes, and developed with their 'Universal' developer. The tube was about 9 in. above the hand. An example of a chopper cut to the middle finger, and of strumous dactylitis in the metacarpal, occurring in one and the same hand, is given at fig. 42. Gerard Smith, Esq., M.R.C.S. London, kindly placed this picture at the author's disposal, as also fig. 43, which shows a case of tubercular disease of the tibia (originating in a twist and blow, the foot having been caught in the flywheel of a heavy sewing machine). By means of the radiograph this gentleman was enabled to verify the existence of a tubercular cavity, accompanied by an almost complete destruction of the healthy 'cancellous' bone. The cavity was opened from above and the contents evacuated. A cure was the result. It may be here mentioned, as a guide to the worker, that these pictures were taken on Edwards' 'cathodal' plates, slowly developed with pyro-soda, along with metubisulphite of soda, but *no* bromide. The development took half an hour to complete, rocking the whole time. The tube used was a bianodic, working with about 9 in. spark. The distance from the tube to the foot was 2 ft., the exposure five minutes only.

Fig. 44 is a radiograph of the knee and its cap; while fig. 45 shows the human pelvic basin. This latter,

owing to the thickness of the fleshy portions, is rather a difficult object to take successfully, as in order to get sharp outlines of the bones, without distortion, the tube must be at some distance. By kind permission of M. Gaston Seguy, of the Radiographic Institute of France, we are enabled to reproduce these. M. G. Seguy is an enthusiastic worker in this direction, and has just communicated to the author the result of some experiments, which tend to prove that by coating or staining the tube with certain materials, either in the form of fine powder or otherwise, it is possible so to modify the vibration rate of the effluent rays as to enable a radiograph to be taken in a very much shorter time than without.

Mr. George Avery, whose photo-micrographic work is second to none, has been equally successful in radiography; and among the many beautiful pictures he kindly placed at our disposal for reproduction we have selected fig. 46, which shows the relative transparency of various substances to the X rays. The exposure given was $2\frac{1}{2}$ minutes on a rather slow plate. The square marked 1 is the faint image given by mica, 2 is a piece of wood, 3 is tinfoil, 4 is a vulcanite disc, 5 is a brass disc, 6 is the image given by the tooth of a horse, 7 a brass medal, 8 a piece of cork, 9 is a thin micro-covering glass; by comparison it is seen to be almost as opaque to the rays as the vulcanite No. 4.

No. 10, which is a piece of india-rubber, is interesting as showing the difference of X ray transparency imparted to the rubber, by the addition of sulphur, as

in No. 4 and No. 12. No. 11 is a steel spring, and No. 12 a vulcanised india-rubber ring.

Fig. 47 is a radiograph of a mouse. This was taken on a Cadett 'Lightning' plate, the tube being 6 in. from the mouse, with an exposure of 1 minute. The developer used was the old 'ferrous oxalate.'

FIG. 40.—RADIOGRAPH THROUGH HUMAN CHEST.

FIG. 41.—HAND WITH SHOT IMBEDDED.

Fig. 42.—Strumous Dactylitis.

FIG. 43.—DISEASED TIBIA.

FIG. 44.—KNEE AND CAP.

FIG. 45.—HUMAN PELVIC BASIN.

FIG. 46.—DEGREES OF TRANSPARENCY.

FIG. 47.—RADIOGRAPH OF MOUSE.

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